SEMI-ANNUAL TECHNICAL REPORT

An Investigation of Seismic Wave Propagation in Eastern North America

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Seismic waves propagated and recorded at regional distances in eastern North America are being studied for possible use in discriminating between explosion and earthquake sources.

In particular this report deals with:

a. the propagation characteristics of the regional seismic wave designated L_g, and

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(b) an evaluation of the usefulness of a particular ocean bottom seismograph system as an aid in discrimination of seismic sources at regional distances.

The results of the study of the propagation characteristics of L_g with predominant frequencies of 1-3 hertz, is consistently the largest amplitude portion of the short period signal from the Eastern North American events studied.

An analysis of the group velocity for each event studied shows a clustering of measurements in the 3.47 km/sec range for the earthquakes studied and a significantly lower 3.24 km/sec mean for ~~the~~ measurements from the SALMON explosion. This lower value is believed to be the result of propagation path or source effects. E(l) E(h)

When group velocity information was divided into two regions, E_h --high group velocity (4.0-3.4 km/sec) energy and E_l --low group velocity (3.4 -2.8 km/sec) energy, the ratios of these areas showed a discrimination between SALMON ($(E_h/E_l) < .5$) and the earthquakes ($(E_h/E_l) > .5$).

Phase velocity measurements made using records from Cumberland Plateau Seismic Observatory have a mean of 4.18 km/sec. ~~An~~ analysis of a second event also yields measurements in the 4.0-4.4 km/sec range. These measurements fall within the range of phase velocities expected for Rayleigh waves in support of the idea that $L_g(Z)$ is made up of Rayleigh waves.

M_s-m_b measurements made on NTS and Aleutian events as recorded on an ocean bottom seismograph indicate a clear separation of the explosion events from earthquakes. Measurement of M_s or long period energy content could also be made from suitably filtered hydrophone records.

((E(h)/E(l))

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Technical Report Summary

The purpose of this research is to enhance our understanding of seismic wave propagation at regional distances particularly in Eastern North America and to utilize that enhanced understanding to develop methodologies and criteria for distinguishing earthquakes from underground nuclear explosions using seismograph recordings. This report deals with:

a. the propagation characteristics of the regional seismic wave designated L_g, and

b. an evaluation of the usefulness of a particular ocean bottom seismograph system as an aid in discrimination of seismic sources at regional distances.

During this contract period, the primary methodology has been the examination of seismograms to determine the regional propagation characteristics of high frequency L_g.

The principal technical results are:

1. L_g is consistently the largest amplitude portion of the short period signal from the Eastern North American events studied (Table I, pp. 5) as recorded in Eastern North America. $L_g(Z)$ - the vertical component - with predominant frequencies of 1 to 3 hertz is observed consistently in Eastern North America at distances of 5° to 20°.

2. The individual station group velocities for SALMON and the average value 3.24 km/sec are significantly lower than those for the earthquakes studied, based on measurements of the group velocity of the maximum amplitude waves in L_g for 19 Eastern North American events. The earthquake measurements tend to cluster around a mean of 3.47 km/sec (Fig. 1,2, and 3, pp. 6,7 and 8). The lower group velocities for SALMON can be attributed to propagation path effects or source effects. The hypothesis here is that the low velocities are at least partially related to the depth of the source. If $L_g(Z)$ is a superposition of fundamental and higher mode Rayleigh waves, then the excitation of modes should be affected by the source depth with relatively greater excitation of the fundamental mode at shallower depths. Since the fundamental mode travels with a slower velocity, the average wave train should be slower for SALMON, a shallow event, as observed.

3. The use of high frequency $L_g(Z)$ as a depth discriminant appears promising based on measurements of energy ratios. Two group velocity windows (4.0 to 3.4 km/sec - high and 3.4 to 2.8 km/sec - low) were selected to encompass the expected group velocities of higher mode and fundamental Rayleigh waves respectively. To evaluate the energy in each of these group velocity ranges on analog records, the area covered by the $L_g(Z)$ in each of the selected group velocity ranges was determined in a manner analagous to the AR method of long period surface waves. More than fifty records from 12 earthquakes and the SALMON explosion were measured in this manner. The ratios of these areas, which are each related to energy in the velocity window, show a discrimination between SALMON ($E_h/E_l < .5$) and the earthquakes ($E_h/E_l > .5$) (Fig. 16, pp. 24). Plotting these area values against each other the separation is also apparent (Fig. 14,15, pp. 22,23). If the earthquakes occur at all depths within the crust or the upper crust, then we would expect a range of values encompassing the SALMON values and increasing progressively with depth.

4. Phase velocity measurements of L_g have been made using data from the Cumberland Plateau Seismic Observatory and those data indicate a mean phase velocity for L_g of 4.18 km/sec (Fig. 19, pp. 29) for an earthquake in Southern New England. Velocities of 4.0 to 4.4 km/sec were obtained for another event in Southern Quebec. These measurements fall within the range of phase velocities expected for Rayleigh waves thus corroborating the idea that $L_g(Z)$ is made up of Rayleigh waves. Further measurements with arrays of suitable dimensions and theoretical calculations are needed to validate this conclusion.

5. M_s-m_b measurements made on NTS and Aleutian events as recorded on an ocean bottom seismograph system 7.7° from ETS indicate a clear separation of the explosion events from the earthquakes (Fig. 22, pp. 35). Measurements of M_s or long period energy content could also be made from suitably filtered hydrophone records. For the Point Arena, California, ocean bottom system, the lowest body wave magnitude observed was 5.3, but, with suitable modification of the long period response, at least an order of magnitude improvement in the detection threshold should be possible.

Introduction

This report deals with the significant results of a study initiated in December, 1977, to analyze seismic wave propagation in Eastern North America. Particular research efforts in this study include:

1. The investigation of the regional propagation of high frequency L_g with special emphasis on frequency content, propagation velocity and attenuation characteristics as well as the presence or absence of L_g on particular seismograms.

2. The investigation of the regional propagation of continental first and higher mode Love and Rayleigh waves particularly the shape of group velocity curves and attenuation characteristics.

In addition to these studies in the eastern part of the continent, a evaluation of the Point Arena, California, Ocean Bottom Seismograph (OBS) system is being carried out to determine the usefulness of this instrument for detection and identification of Nevada Test Site (NTS) explosions and comparable earthquake events and, more generally, the usefulness of OBS systems in the discrimination of sources at regional distances in specific geographic areas.

The goal of this research is to discover and evaluate the use of discriminants involving seismic waves observed at regional distances, to determine the geographic variations in the parameters used in those discriminants and to understand the propagation of regional seismic waves. Although the discrimination of underground nuclear explosions from earthquakes at teleseismic distances is generally understood above a certain magnitude threshold, the problem of discrimination between the two types of sources at regional distances (5° - 20°) has not, until recently, been examined in detail. However, early work in the VELA-UNIFORM program and some recent work have indicated that discrimination will undoubtedly be more difficult at the shorter distance ranges. Nonetheless, if regional discrimination criteria can be developed and, if high quality land-based stations at regional distances are available, discrimination at significantly lower magnitude thresholds becomes a definite possibility.

The solution of the discrimination problem requires a detailed understanding of the propagation characteristics of seismic waves along the path(s) between the source and the receiver as well as an understanding of the explosion and earthquake sources under investigation. This study is an investigation into certain aspects of these parameters in the Eastern United States (and adjacent areas) - an area which may be geologically and tectonically similar to stable areas in other parts of the world.

1. Propagation of high frequency L_g

At regional distances in Eastern North America (ENA), a seismic signal with predominant frequencies of 1 to 3 hertz propagating with a group velocity of approximately 3.5 km/sec is commonly the largest amplitude signal recorded on conventional World Wide Standard Station Network (WWSSN) or special purpose (higher frequency) instruments. In an earlier report, data for Eastern United States events has been presented which indicate that L_g amplitudes are 6 to 10 times larger than P amplitudes at the same station in Eastern North America. In this area, (or in areas of similar propagation characteristics), the use of L_g as part of (or all of) an identification criteria could result in a significant lowering of the discrimination threshold. At the same time, although the L_g phase has been recognized for years, relatively little is known regarding the characteristics of its propagation. It probably represents the result of a superposition of fundamental and higher mode surface waves - (L_g(Z) - vertical (Rayleigh) and L_g(H) - transverse (Love)). L_g propagation has been investigated using the 19 ENA earthquakes listed in Table I together with information on source parameters. Also in Table I, the analyses performed on the data have been indicated and these analyses will be discussed separately below.

A. Group velocity

The group velocities of the maximum amplitude signal within the L_g phase were read for each of the nineteen earthquakes listed in Table I from records of the WWSSN and from records of the Northeastern United States Seismic Network (NEUSSN). Several examples of these recordings are presented in Appendix A (Figures A-1 to A-7). The results of all of these measurements are plotted as a function of epicentral distance in Figure 1 to Figure 3 . Figure 1 shows the results for the events indicated as recorded at stations of the NEUSSN network, Figure 2 shows data for the listed earthquakes recorded at the University of Minnesota array, the Wich-

TABLE I

Event	Date	Origin Time	Latitude	Longitude	Magnitude	Location	Analyses Performed: Group Vel.	Phase Vel.	Energy Ratios
1	06/15/73	01:09:05	45.390°	71.000°	m_b=5.2 m_N=4.9	Maine-NH Quebec Border	x		x
2	01/08/74	01:12:37.4	36.20°	89.39°	4.1 4.3(S)	Tennessee	x		
3	02/15/74	22:35:44.7	34.05°	93.13°	4.2 3.6(S)	Arkansas	x		
4	04/03/74	23:05:02.5	38.59°	88.09°	4.5 4.7(S)	S.Illinois	x		
5	06/05/74	08:06:11.3	38.62°	89.94°	4.0 3.6(S)	S.Illinois	x		
6	06/13/75	22:40:27.2	36.54°	89.68°	4.3	Missouri	x		
7	07/09/75	14:54:15.1	45.67°	96.04°	4.6 4.3(S)	Minnesota	x		x
8	07/12/75	12:37:16	46.467°	76.222°	4.1m_N	Maniwaki	x		
9	08/29/75	04:22:51.9	33.82°	86.60°	3.5 4.4(S)	Alabama	x		x
10	10/23/75	21:17:48.2	49.689°	68.822°	4.0m_N	Manicouagan	x		x
11	10/23/76	20:58:18	47.492°	69.474°	4.4m_N	St. Simeon/ Quebec	x		
12	10/15/63	12:28:58.4	46.6°	77.6°	<3m_b	Southern Quebec	x	x	x
13	10/16/63	15:31:01.8	42.5°	70.8°	<3m_b	Southern New England	x	x	x
14	10/10/63	14:59:52.5	39.8°	78.2°	<3m_b	Virginia	x		x
15	05/04/63	21:01:35.9	32.2°	79.7°	<3m_b	S.Carolina	x		x
16	12/04/63	21:32:35.1	43.6°	71.5°	<3m_b	Northern New England	x		x
17	12/05/63	06:51:02.5	37.2°	87.0°	<3m_b	Kentucky	x		x
18	02/16/78	14:48:25.3	46.31°	74.37°	4.2	Canada	x	x	x
19	08/14/65	13:13:56.6	37.23°	89.28°	3.8m_b	S.Illinois	x		x
SALMON	10/22/64	16:00:00	31.14°	89.57°	5.3-kt	Mississippi	x	x	x

List of Eastern North American events used in the L_g study

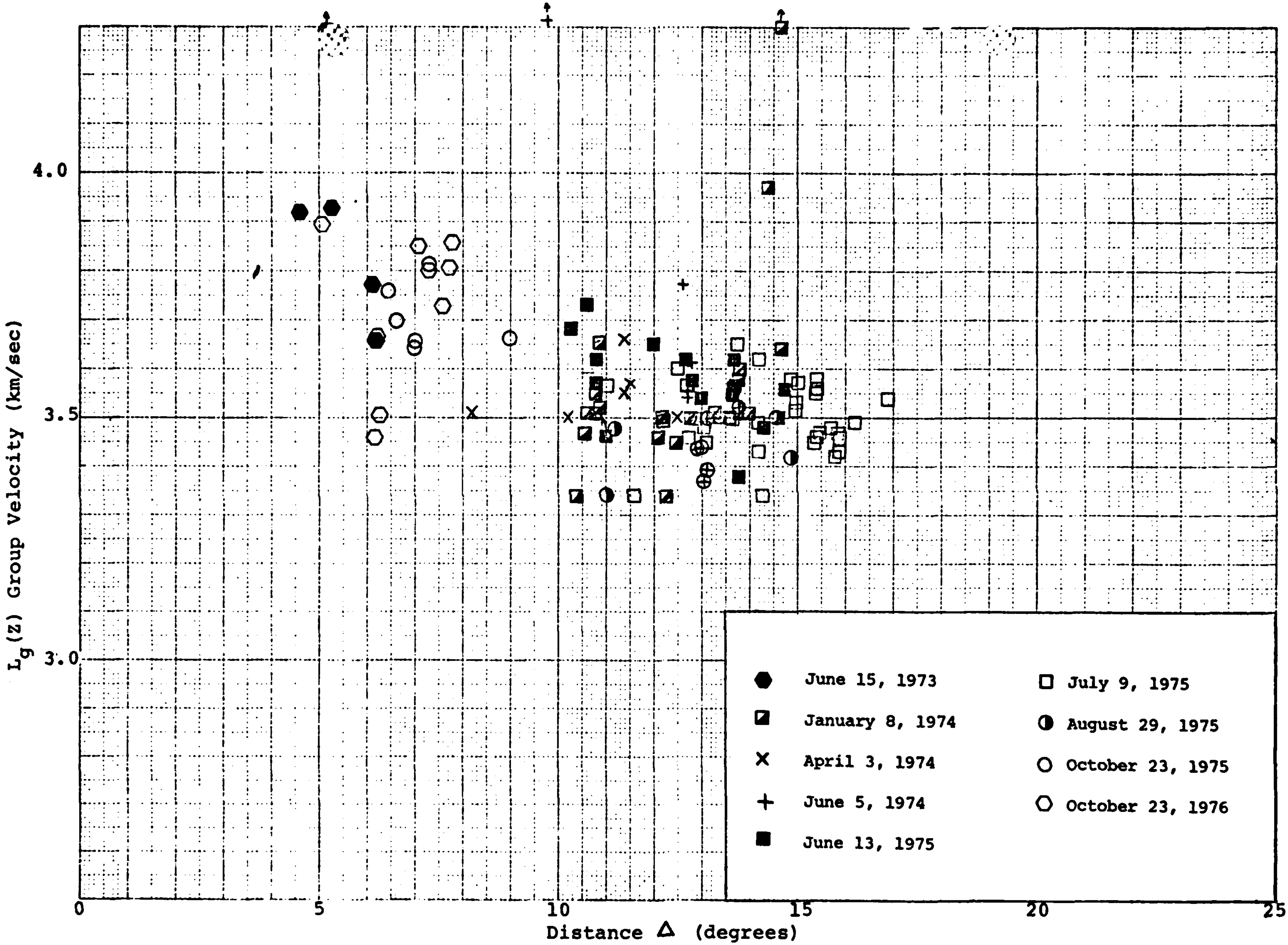


Figure 1. L_g(Z) group velocity vs. distance as determined from NEUSSN station data.

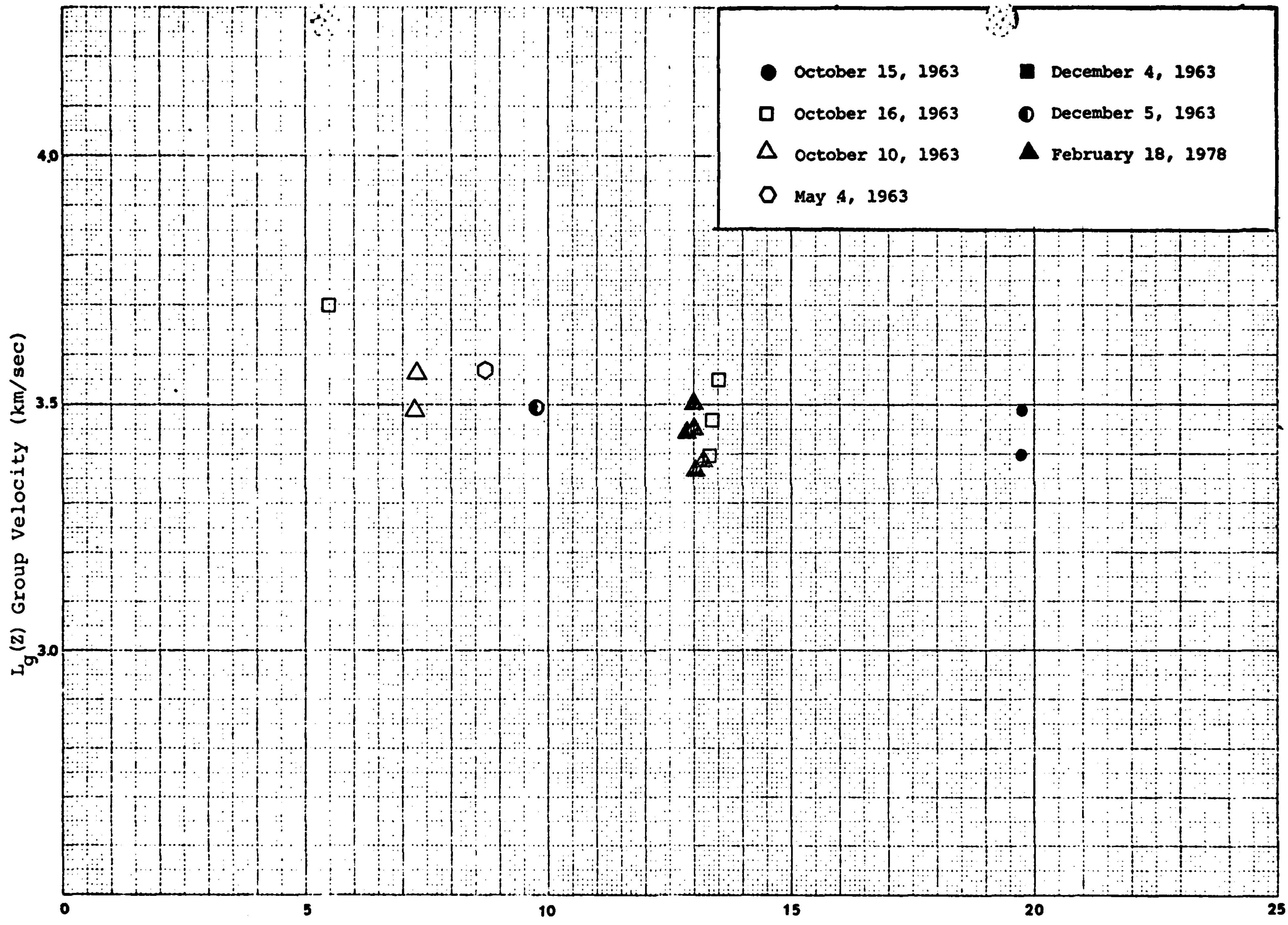


Figure 2. L_g(Z) group velocity vs. distance as determined from U. Minnesota, WMSO, CPSO and WWSSN data.

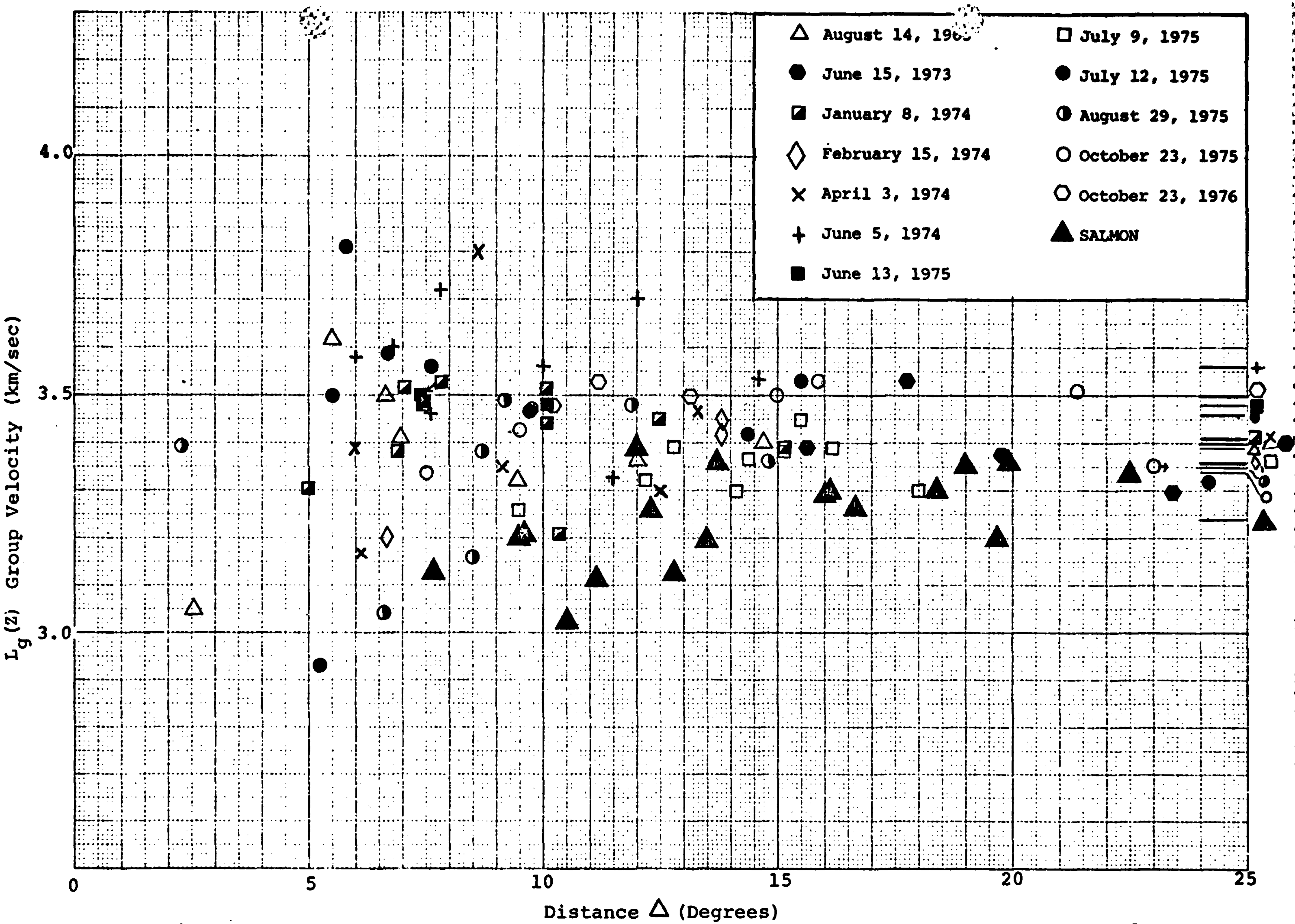


Figure 3. L_g(Z) group velocity vs distance as determined from the WWSSN and LRSM data. Bars on the right hand side represent averages determined for each set.

ita Mountain and Cumberland Plateau Seismic Observatories (WMSO and CPSO) and the WWSSN stations and Figure 3 shows the data for the earthquakes listed and the SALMON explosions as recorded at WWSSN and Long Range Seismic Measurements (LRSM) stations. In general, these measurements are in agreement with data reported by Nuttli, Street and others for the Eastern United States; that is, the mean value for any given event falls in the vicinity of 3.5 km/second. Of far greater significance, however, is the fact that, in general, the data points for SALMON fall below most of the group velocities of the earthquakes studied. On the right hand side of Figure 3 a number of horizontal lines, each identified with an event symbol, can be seen. Each line represents the average of the group velocity measurements for that particular event. SALMON shows the lowest average group velocity - 3.24 km/sec. In order of increasing group velocity the events are:

Date	Velocity km/sec	
October 23, 1975	3.34	
August 29, 1975	3.35	
February 15, 1974	3.36	
July 9, 1975	3.36	
August 14, 1965	3.39	a shallow event h=1-2 kms.
June 15, 1973	3.40	
January 8, 1974	3.41	
April 3, 1974	3.41	
July 12, 1975	3.46	
June 13, 1975	3.48	
October 23, 1976	3.50	
June 5, 1974	3.56	

With the exception of the August 14, 1965, event, depths for these events are not well determined.

Variations in group velocity can be related to variations in velocity structure or other propagation path effects or to source variations. For long period (> 2 seconds) surface waves, group velocity variations are related to variations in velocity structure and have been used extensively to characterize various regions. To study the effect of propagation path on group velocity here, we have plotted the value of the group velocity of the maximum amplitude of L_g along each propagation path involved and these maps of the group velocity are presented in Figures 4 to 12. A comparison of the SALMON data (Figure 4) with the nearest events - August 29, 1975 in Alabama (Figure 5)

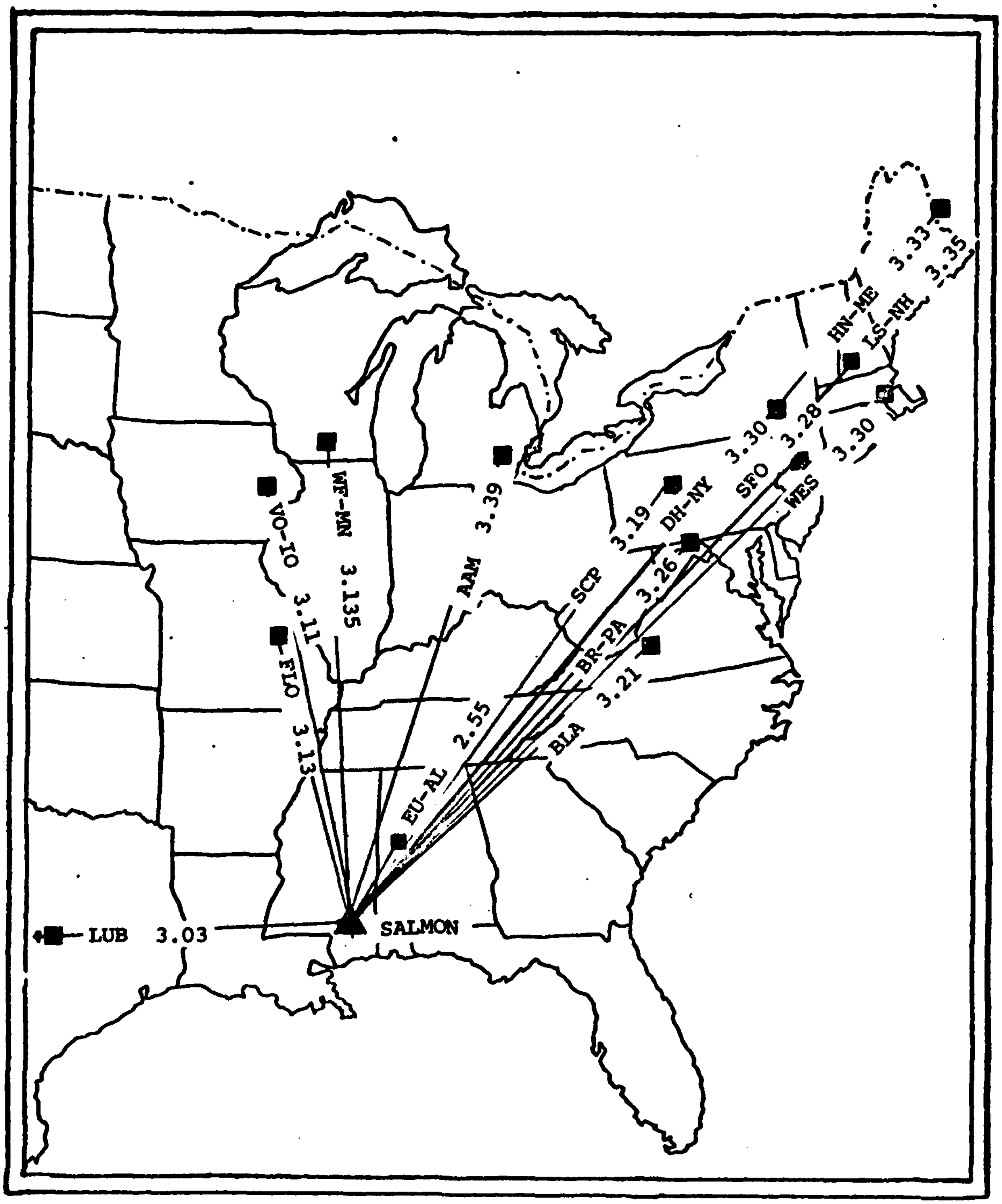


Figure 4. $L_g(Z)$ group velocity measurements for the SALMON explosion plotted along propagation paths.

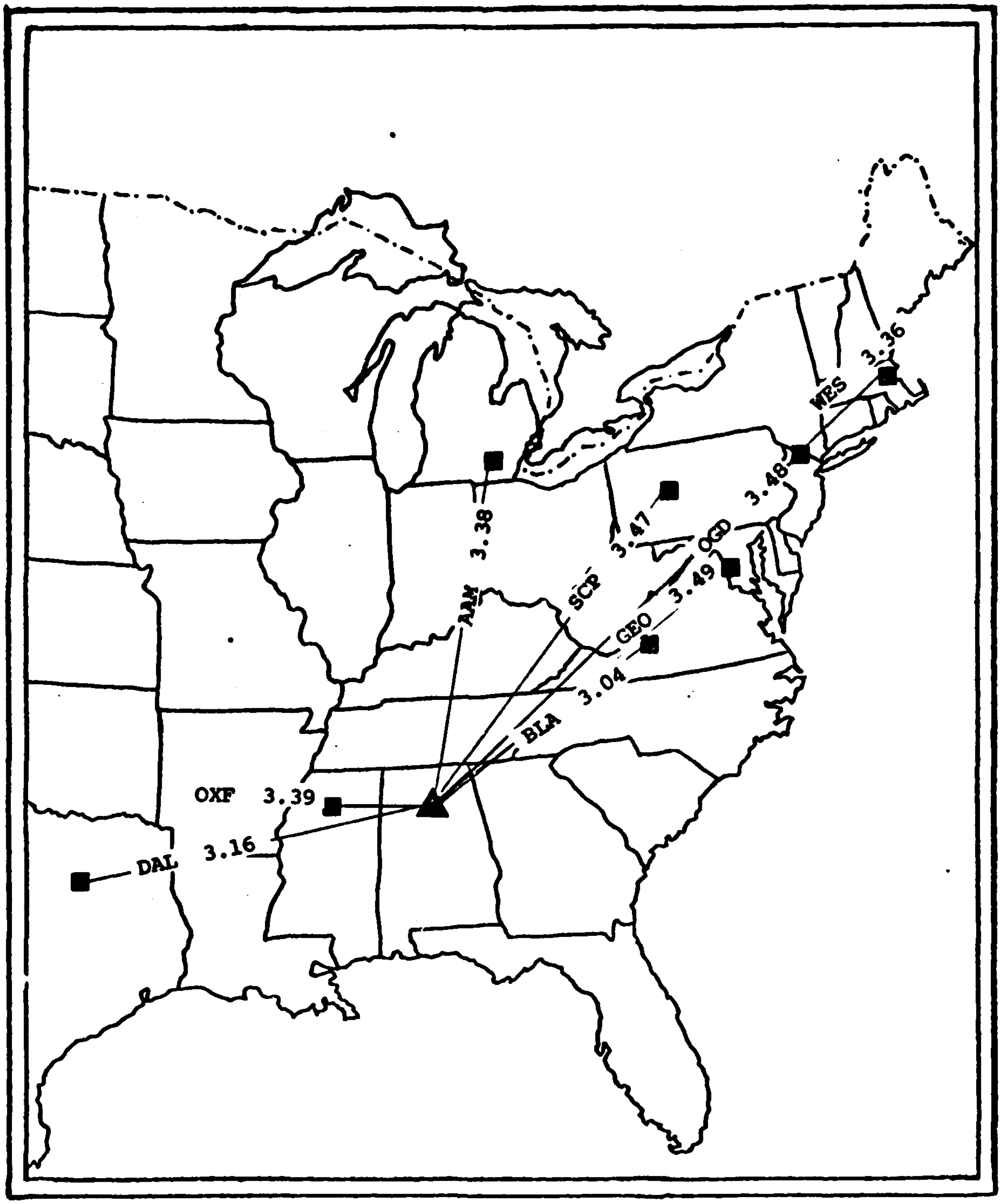


Figure 5. $L_g(Z)$ group velocity measurements for the August 29, 1975 earthquake plotted along propagation paths.

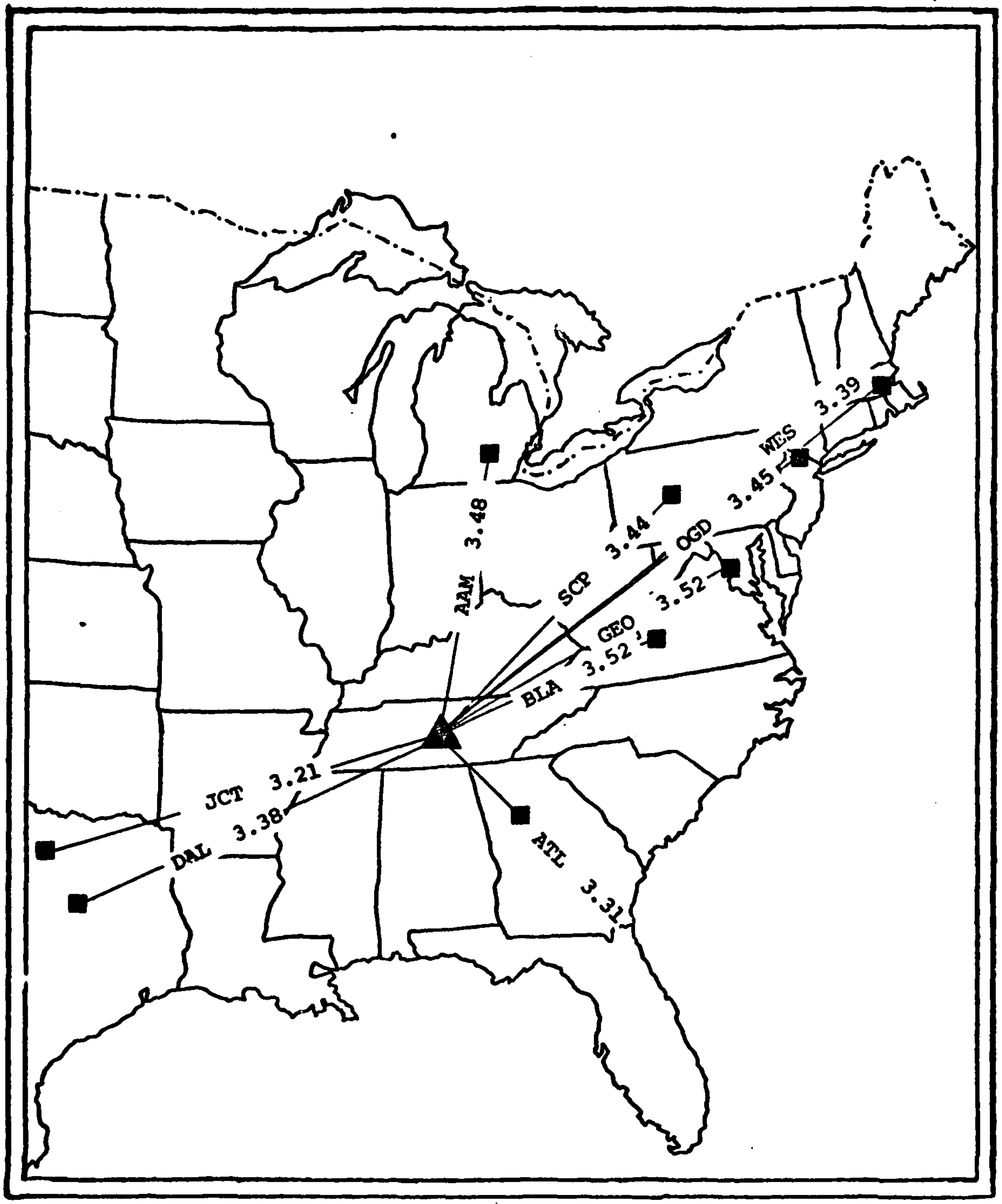


Figure 6. L_g(Z) group velocity measurements for the January 8, 1974 earthquake plotted along propagation paths.

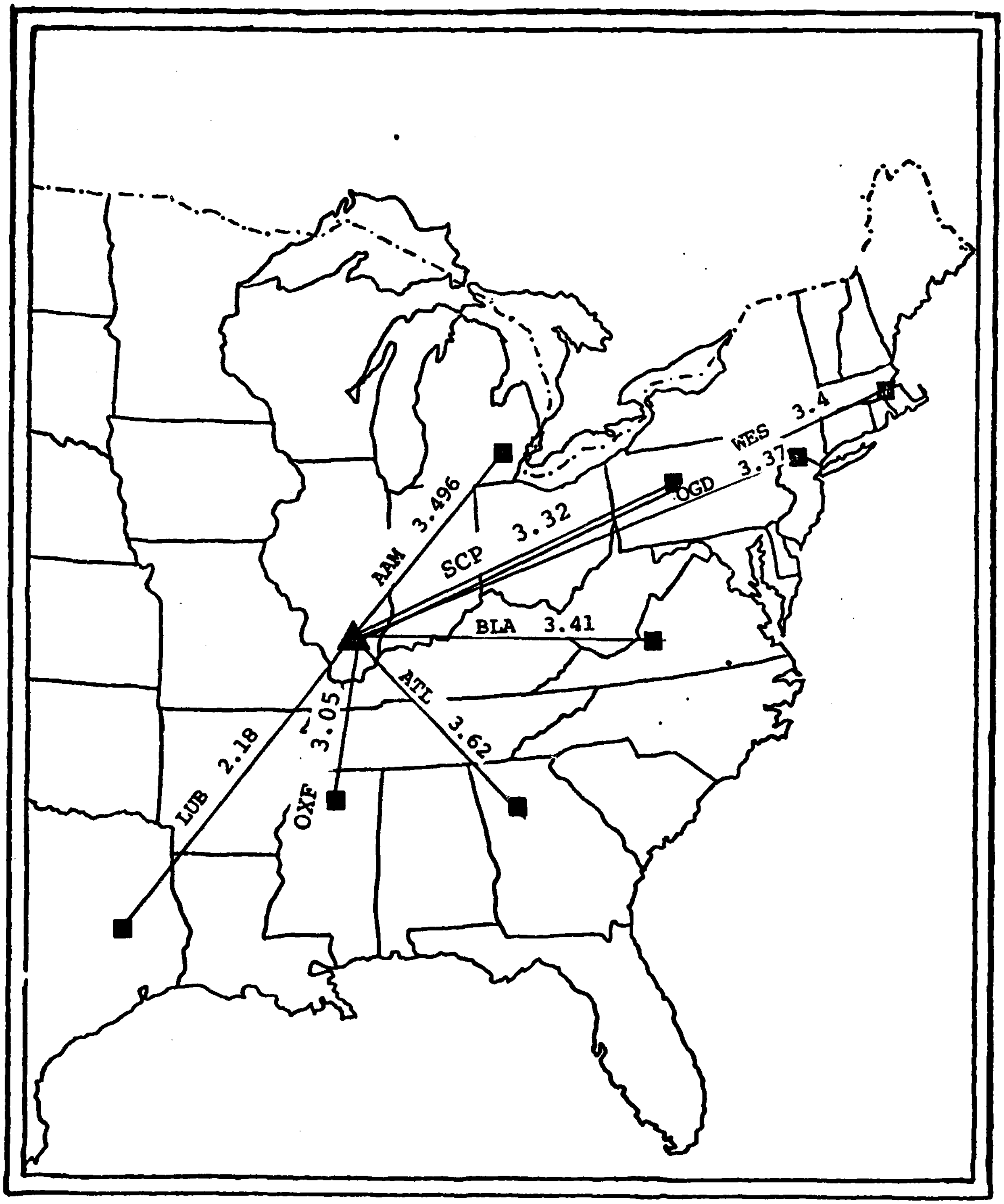


Figure 7. $L_g(Z)$ group velocity measurements for the August 14, 1965 earthquake plotted along propagation paths.

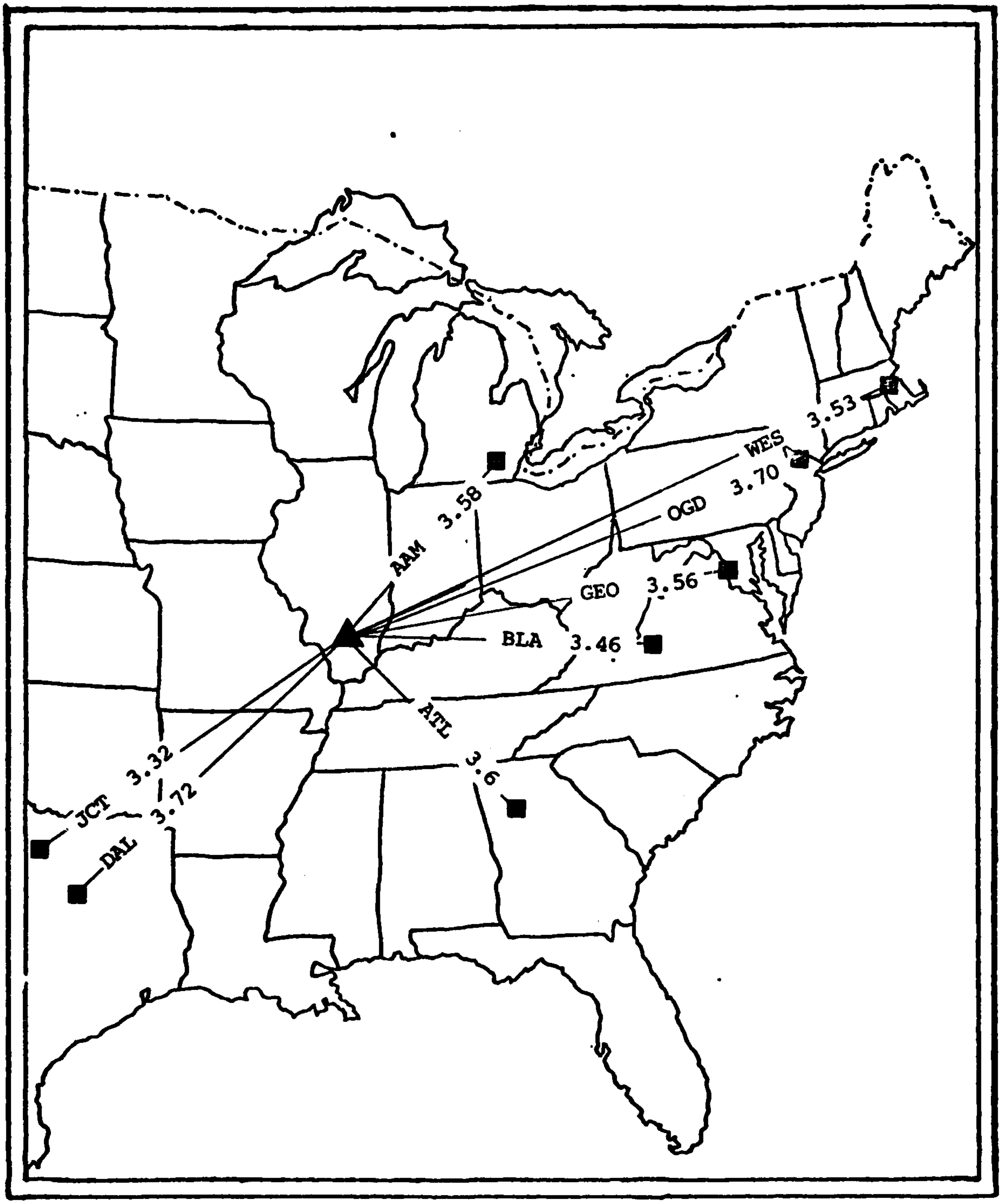


Figure 8. $L_g(Z)$ group velocity measurements for the June 5, 1974 earthquake plotted along propagation paths.

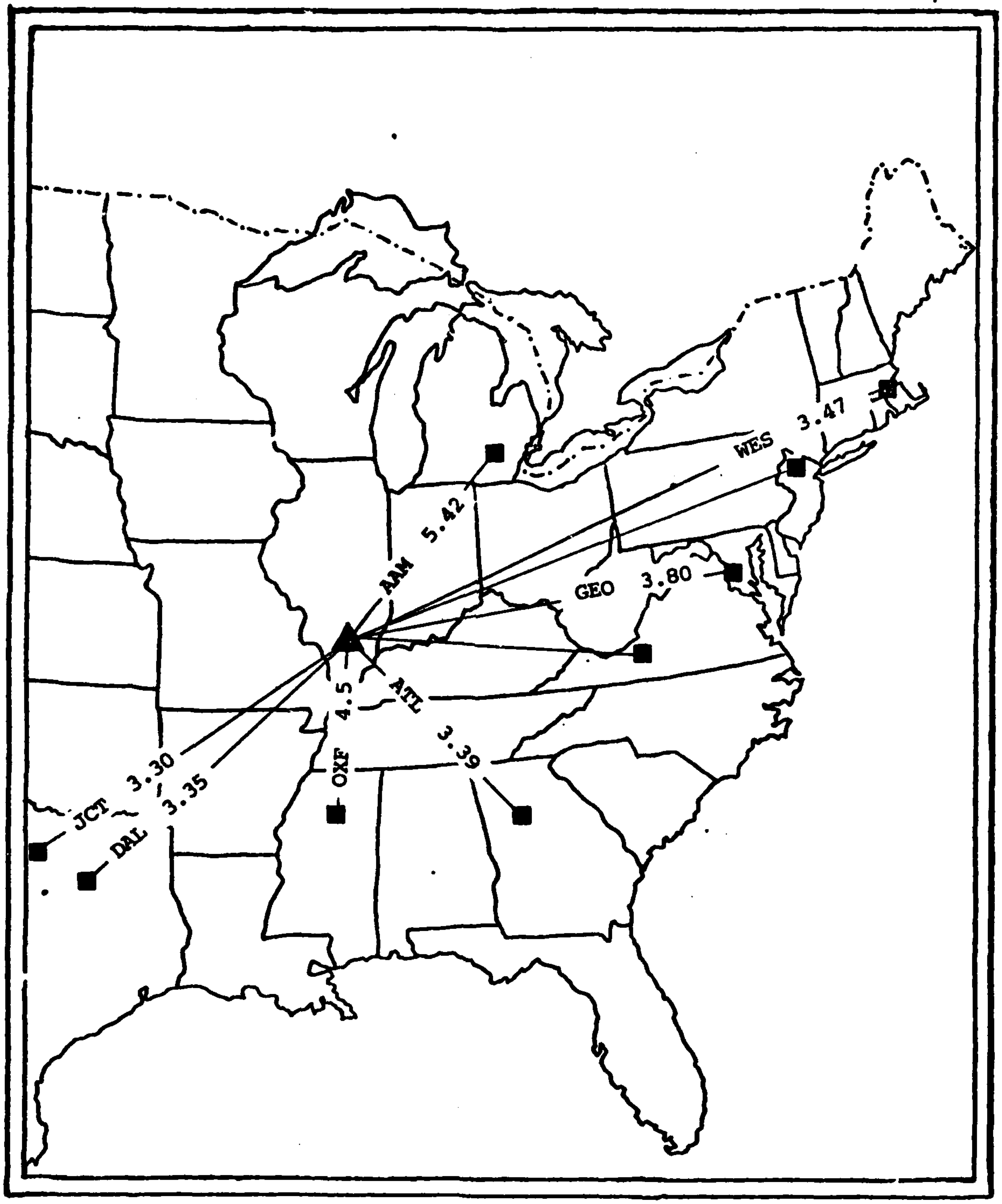


Figure 9. $L_g(Z)$ group velocity measurements for the April 3, 1974 earthquake plotted along propagation paths.

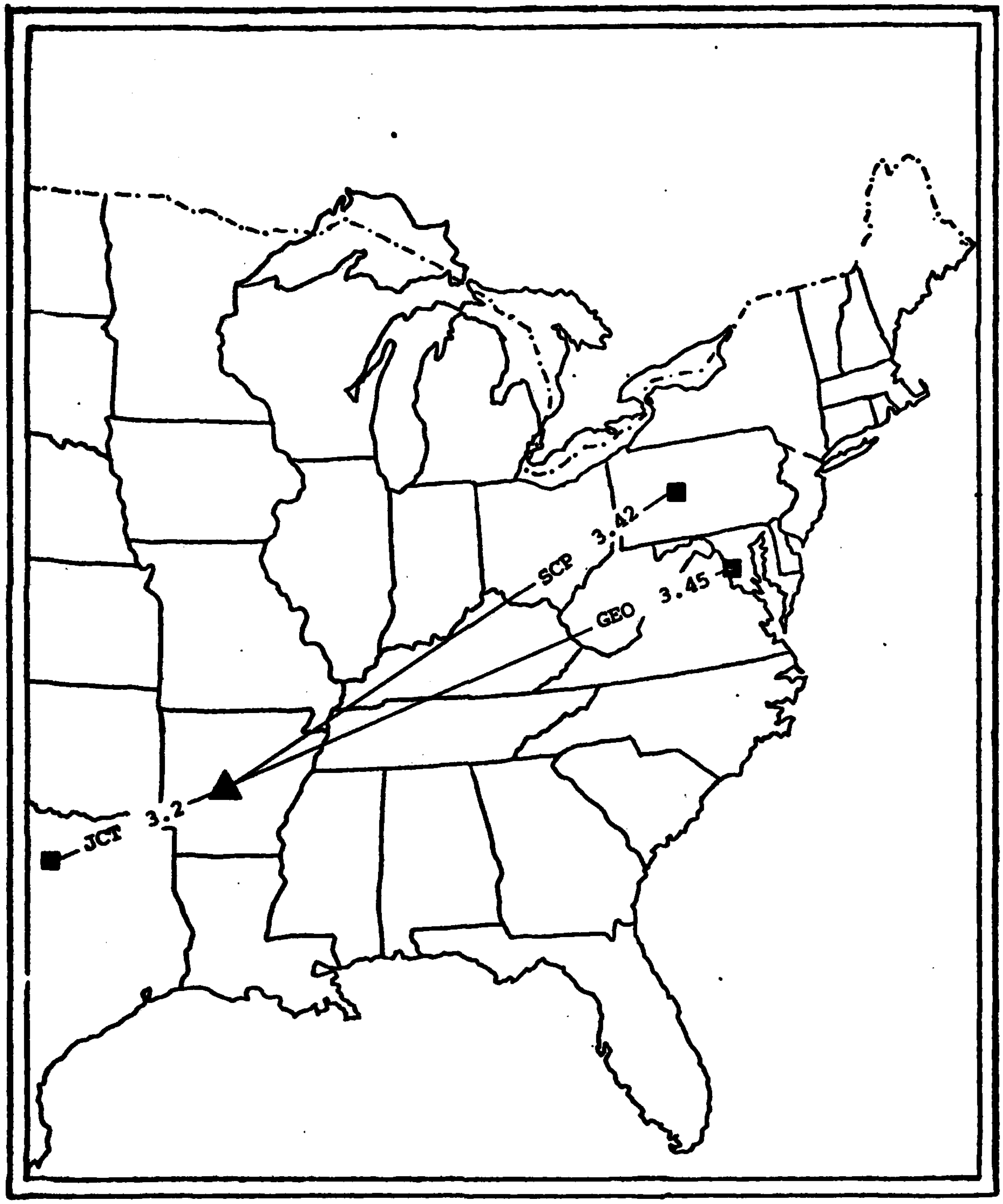


Figure 10. $L_g(Z)$ group velocity measurements for the February 15, 1974 earthquake plotted along propagation paths.

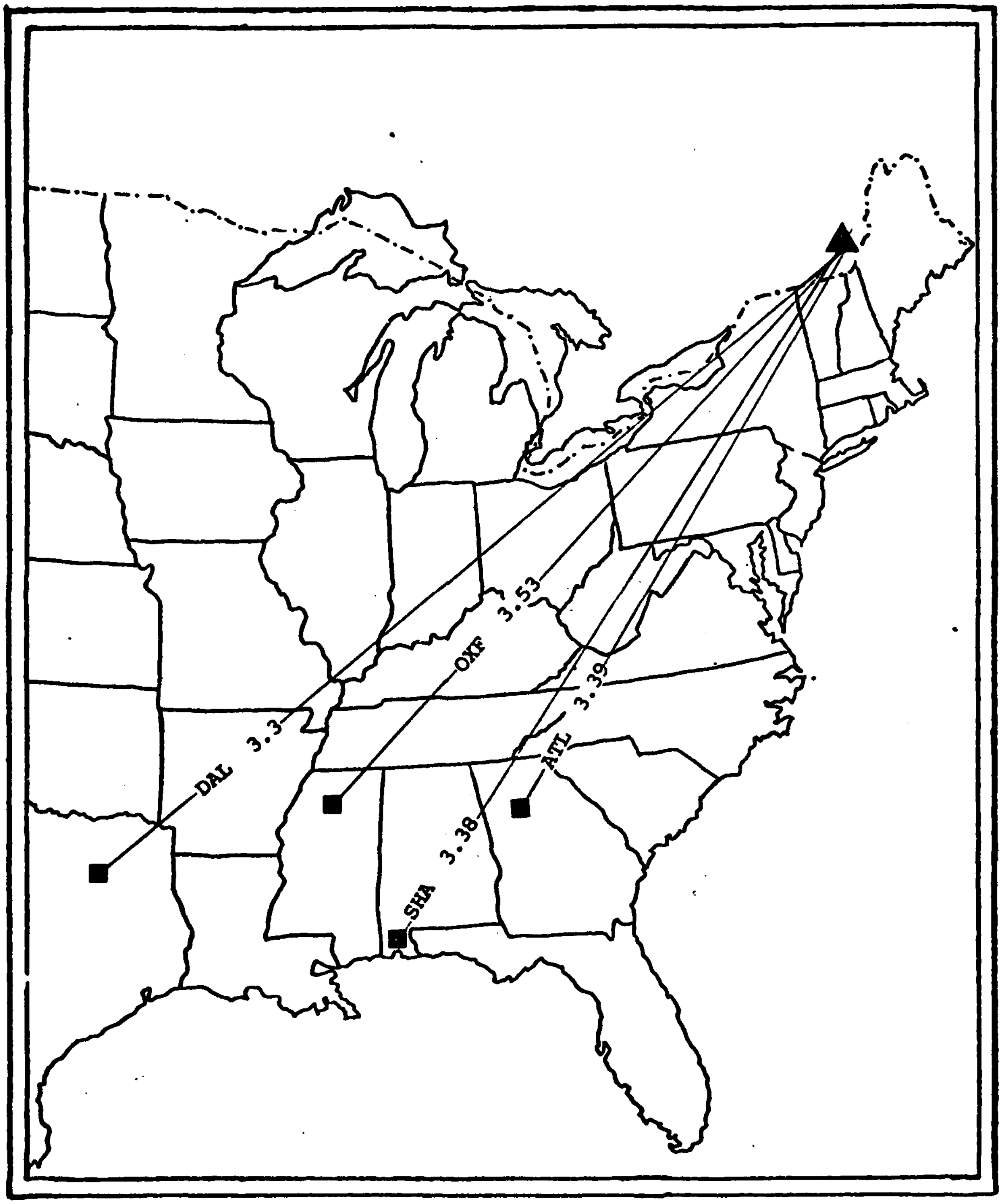


Figure 11. $L_g(Z)$ group velocity measurements for the June 15, 1973 earthquake plotted along propagation paths.

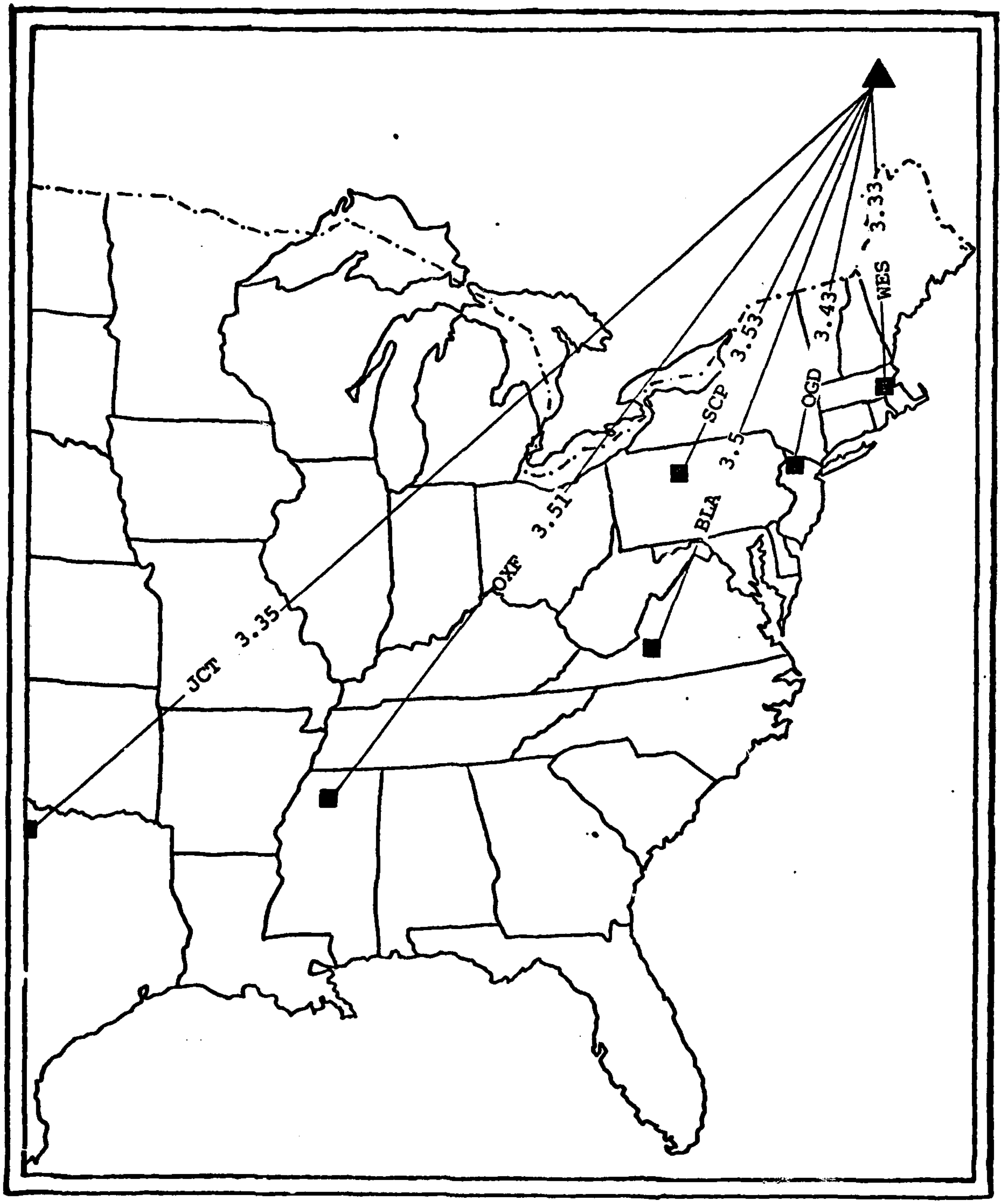


Figure 12. $L_g(Z)$ group velocity measurements for the October 23, 1975 earthquake plotted along propagation paths.

and January 8, 1974 in Tennessee (Figure 6), as well as northern events with propagation paths to the south along the Appalachians (Figures 11 and 12), does not show that the low average group velocity is exclusively a function of depth, although the average group velocity for the Alabama event is low - 3.35 km/sec and the waves from SALMON traverse an area with a greater thickness of sedimentary cover than do the waves from the Alabama event.

If the low group velocities measured for SALMON are not solely a propagation path effect, then the question arises as to whether they could be related to source parameters, particularly depth of the source. If L_g represents a superposition of fundamental and higher mode surface waves, then the excitation of the various modes can and should be significantly affected by the depth of the source. Herrmann has shown that, for Rayleigh waves, the excitation of the higher modes is relatively uniform with source depth but the fundamental mode is preferentially excited by shallow sources. Nuttli has pointed out that "the excitation of higher mode L_g waves is nearly independent of depth in the crust. However, the excitation of high frequency fundamental mode surface waves is at least one order of magnitude greater for depths of 0 to a few kilometers than for depths greater than 5 kilometers". If this is correct, then for SALMON, a very shallow event, we would expect relatively greater excitation of fundamental mode waves and since fundamental mode waves in the frequency range observed (1 to 3 hertz) propagate with lower group velocity than the higher modes, we would expect lower average group velocities for the SALMON event. However, it is clear that a single point measurement such as the group velocity of the maximum amplitude is not a good characterization of the energy propagation characteristics. To avoid this limitation, the energy ratio technique discussed in the following section was developed.

B. Energy ratios

To evaluate the propagation of energy in the different modes, an energy ratio method was devised. During the examination of records in the group velocity study described above, it was noted that the energy in $L_g(Z)$

was distributed approximately equally about a group velocity of 3.4 km/sec, that is, about half the energy in $L_g(Z)$ traveled with a group velocity greater than 3.4 km/sec and half propagated with a group velocity less than 3.4 km/sec (Figures A-1 to A-6). Two group velocity windows of the same length were selected — 4.0 to 3.4 km/sec and 3.4 to 2.8 km/sec. The faster window encompasses the range of group velocities which might be encountered in the higher Rayleigh modes while the slower window includes group velocity values normally associated with the fundamental Rayleigh mode in this frequency range. To quantify the amount of energy in each group velocity window, the area enclosed by the envelope of the waves was measured with a planimeter in a method analogous to the AR method used on long period surface waves. The areas measured are proportional to the energy carried in the window - and the energy is designated E_h-h for high velocity and E_l-l for low velocity. The energy ratio E_h/E_l can be formed. An example of the technique is presented in Figure 13 for a recording from State College, Pennsylvania, of the South Carolina earthquake of December 4, 1963. The epicentral distance here is 5.5° and the E_h = .75, E_l = .73 and the ratio E_h/E_l = 1.03. Since the dividing line between the two windows, 3.4 km/sec, was chosen because the energies at greater and lesser velocities were approximately equal, the energy ratios should fall around 1 for the earthquakes while for SALMON, with its lower group velocity, i.e., more energy arriving later, the ratio should be lower. The results of the application of this technique are presented in Figures 14, 15 and 16. In Figure 14 E_h/E_l is plotted on a linear scale, while in Figure 15, the data is plotted logarithmically. In Figure 16, the energy ratio, E_h/E_l is plotted as a function of distance. Numerous other examples of the methodology and measurements are presented on eastern United States records in Appendix B (Figures B-1 to B-8).

Referring to Figure 16, the energy ratio values obtained to date for SALMON fall below .5 while the measurements for the eastern earthquakes studied fall above .5. In fact, a continuum of the earthquake data should exist from values less than .5 to much higher values if the hypothesis that the energy distribution is controlled by the source depth is correct and if the earthquakes studied occur at all depths from at least as shallow as

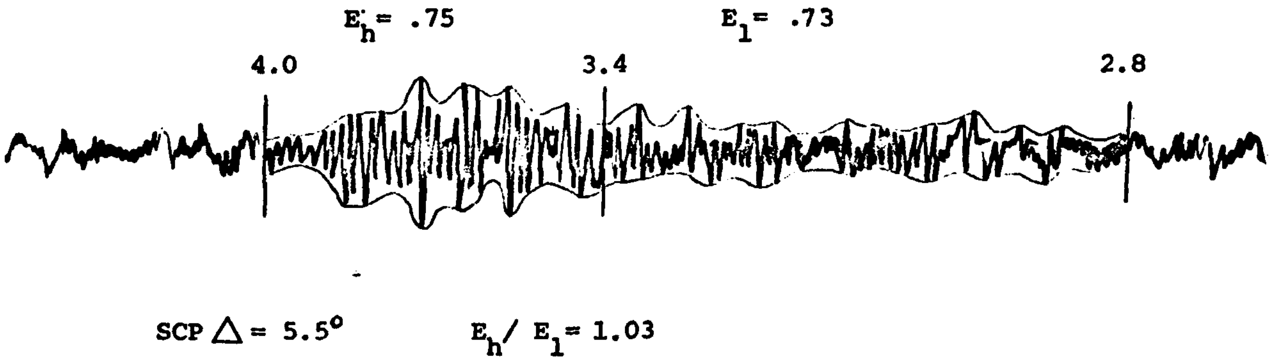


Figure 13. An example of energy ratio determination for the South Carolina earthquake of December 4, 1963 - body wave magnitude < 3.

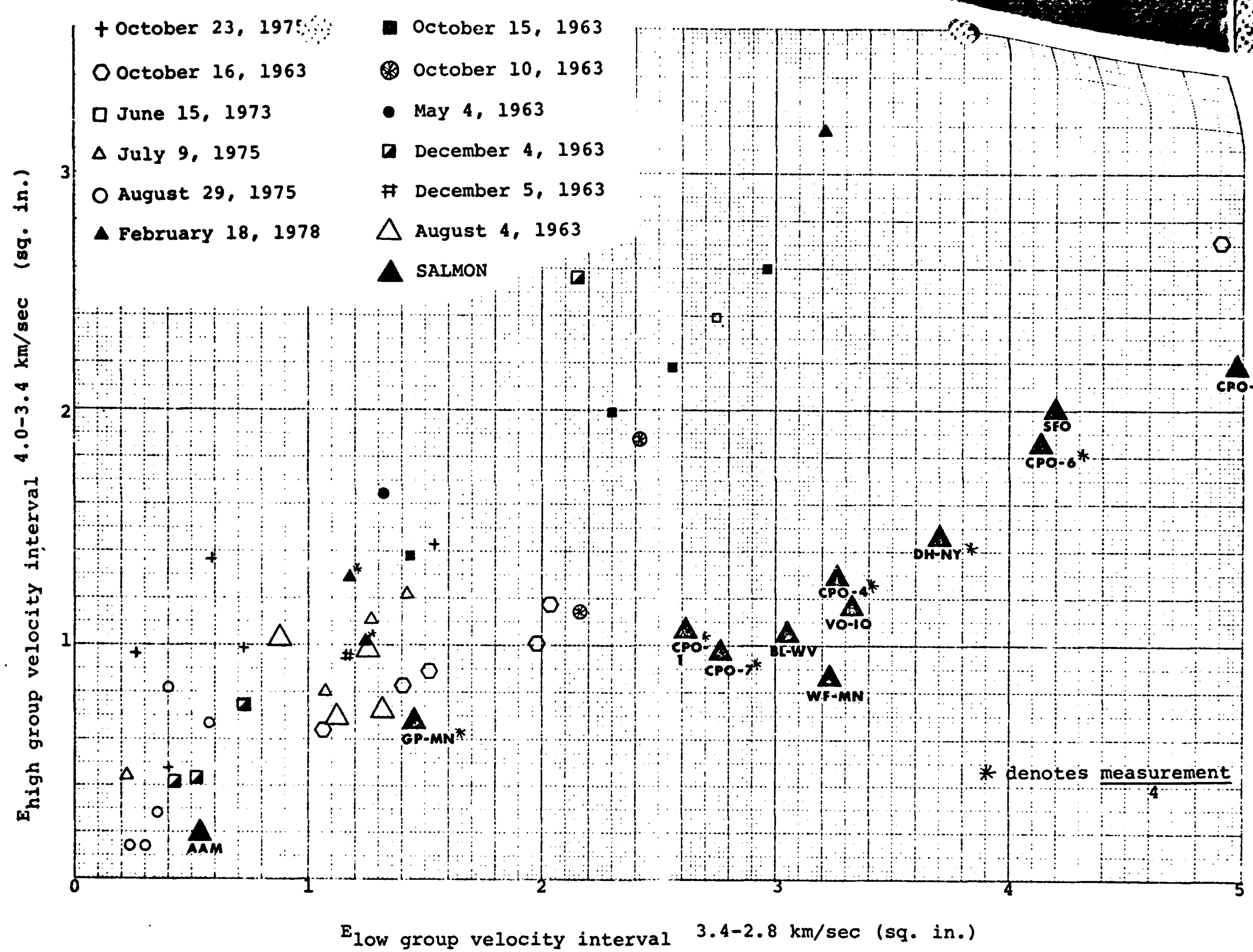


Figure 14. E_h vs E_l for 12 Eastern North American earthquakes and SALMON.

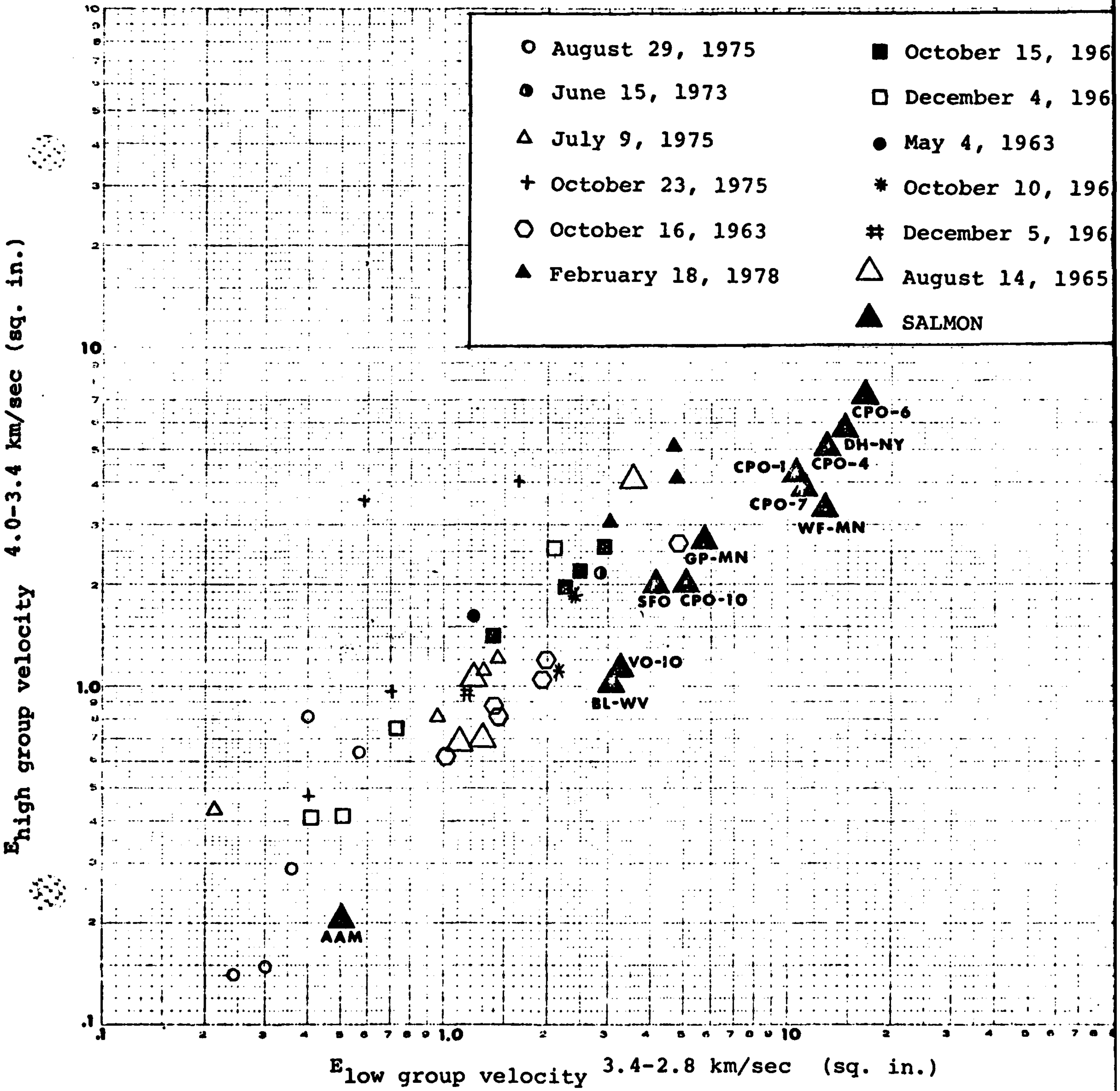


Figure 15. E_h vs E_l for 12 Eastern North American earthquakes and SALMON.

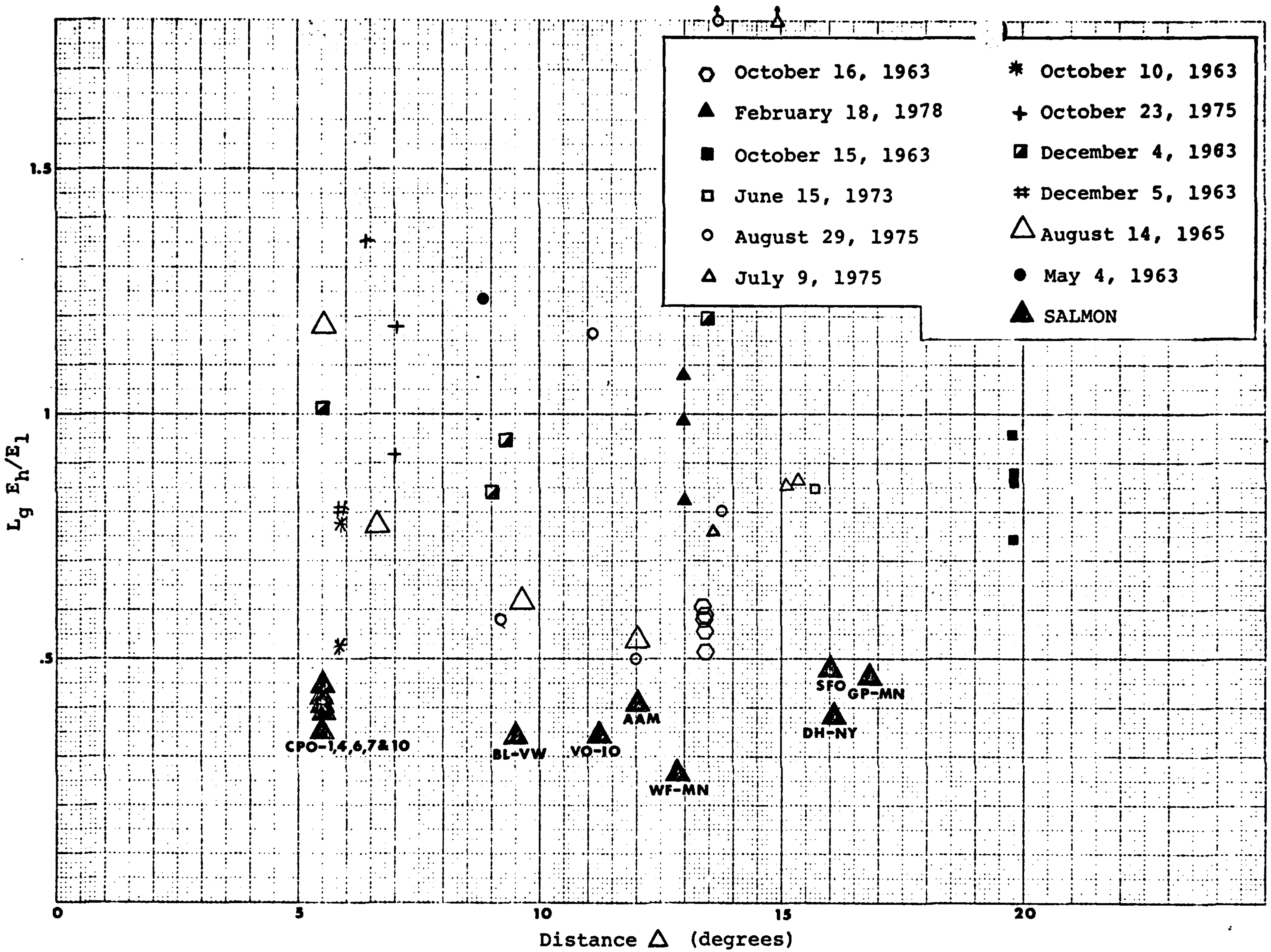


Figure 16. E_h/E_1 vs distance for 12 Eastern North American earthquakes and SALMON.

SALMON to much greater depths. The energy ratio results, as presented, could provide the basis for a depth discriminant. In Figure 16 the SALMON data can clearly be divided from the earthquake population studied especially for the larger measurements; however, a continuum in the data plotted in this manner would also be expected. Nonetheless, this is an exciting result which appears to be very promising particularly in view of the occasional low group velocities reported by Molnar et al (1977) for events in the USSR. Efforts during the remainder of the contract period will be devoted to the elucidation of this effect and further development of its use as a depth discriminant.

Currently an examination of these energy ratios as a function of propagation path is underway using maps such as that shown in Figure 17 for SALMON.

C. Phase velocity

Phase velocity measurements of the L_g phase are essentially nonexistent. However, it is extremely useful to study the phase velocity of waves in the L_g train for at least two reasons:

1. If L_g is useful as all or part of a discrimination technique, then a basic understanding of the mode of propagation of L_g becomes essential. If L_g does represent a superposition of fundamental and higher mode energy, then phase velocity measurements should indicate the composition of the wave train.

2. Since L_g is the largest amplitude signal on the short period seismogram it will, at times, be the only signal recorded. The question of whether $L_g(Z)$ can be used alone as a discriminant can then be posed. In the preceding section, is has been demonstrated that group velocity windows can be used to aid in the discrimination of at least one event (SALMON). The use of group velocity implies a knowledge of the location and origin time of the event. If phase velocity could be used instead of group velocity, the requirement for knowledge of other parameters might be eliminated. Thus, it is instructive to know whether phase velocity measurements can be made.

For these reasons, we have investigated the possibility of determining phase velocity of L_g from Eastern North American earthquakes and SALMON. To obtain data, listings of all Eastern and Central North American earthquakes that occurred from 1963 to 1968 were prepared and then film records of these

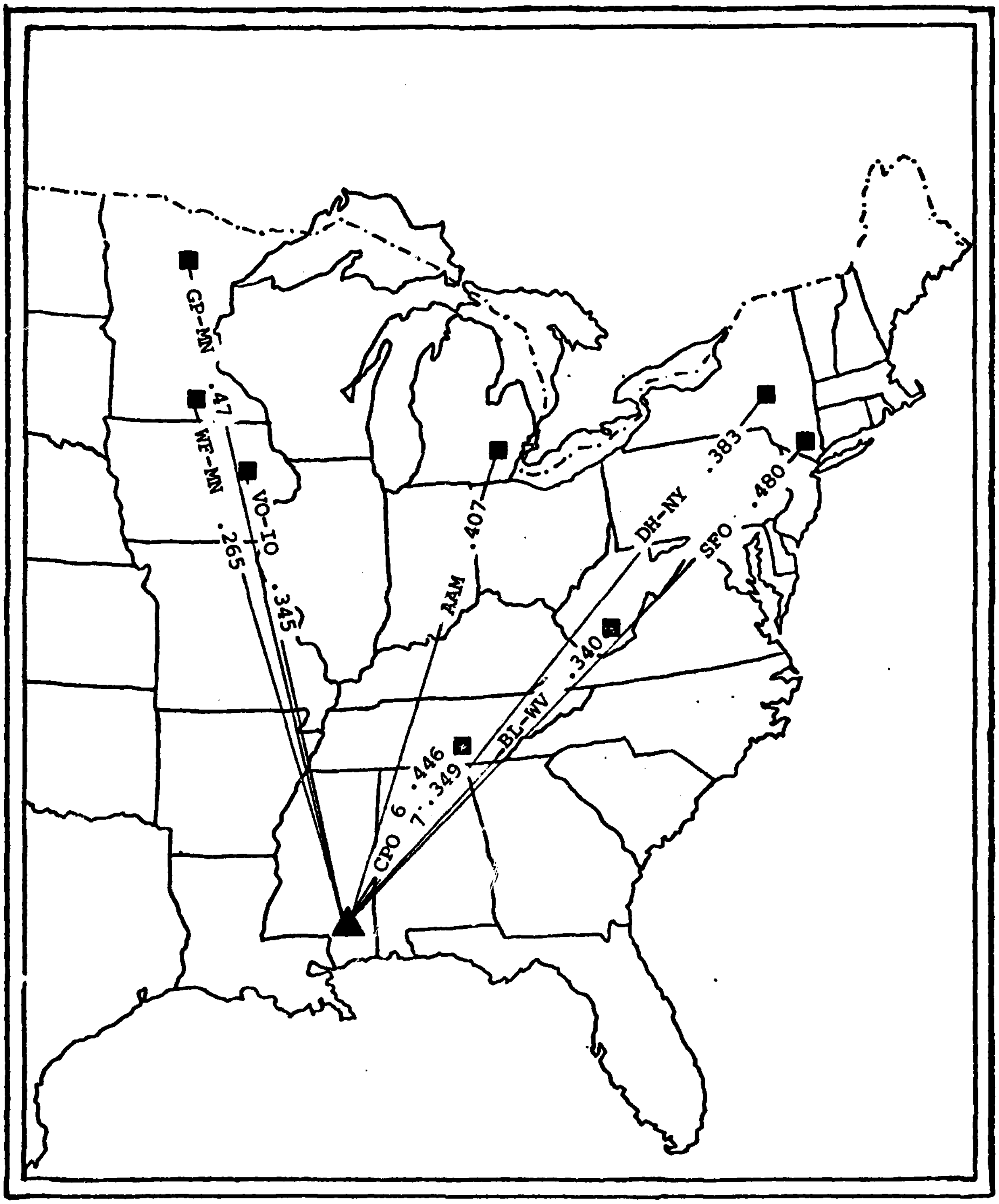


Figure 17. E_h/E_1 energy ratios for SALMON plotted along propagation paths.

events as recorded at the Cumberland Plateau Seismic Observatory (CPSO) and the Wichita Mountains Seismic Observatory (WMSO) were examined. Analog playouts with a time axis of 1 inch/second were then requested for a few specific events from the Seismic Data Analysis Center (SDAC). To date, playouts from two events have been obtained and analyzed. Phase velocities for $L_g(Z)$ were obtained from records from 10 instruments of CPSO for an event in Southern New England which occurred on the 16th of October, 1963 (42.5°N 70.8°W, 0=15:31:01.8 GMT). Correlations were made between two instruments in 10 second intervals which encompassed a group velocity range of 3.8 to 3.16 km/sec. A reduced time scale plot of this CPSO record is presented in Figure 18. A total of 229 measurements are presented in the form of a histogram in Figure 19. The mean of these measurements is 4.18 km/sec which corresponds roughly to the few theoretical calculations for the phase velocity of Rayleigh waves in this period range. These measurements are shown as a function of frequency in Figure 20 and as a function of the spacing between the elements correlated in Figure 21.

A second event which occurred in Southern Quebec (16.6°N 77.6°W, 0=12:28:58.4 GMT) is currently being analyzed. Preliminary results indicate phase velocities fall in the 4.0 to 4.4 km/sec range. Investigations at UKAEA have reported L_g phase velocities of $\sim$4.4 at the Yellowknife array in Canada from a Western United States event at a regional distance. The relative consistency of these values indicates that with arrays of suitable dimensions, L_g phase velocity data can be extracted and, as theoretical calculations become available, the mode of propagation of L_g may be unraveled.

2. Point Arena, California Ocean Bottom Seismograph (OBS) Results

The Point Arena OBS system including 3 component long and short period seismometers operated for a six year period off the coast of California and, during that time, it produced a wealth of seismic information. The system also contained a crystal hydrophone with a long period response and that unit recorded surface waves from a number of seismic events.

Long period records from the Point Arena system have been used to:

A. Evaluate the use of OBS's for M_s-m_b calculations for events at the Nevada Test Site - a distance of about 7 1/2°.

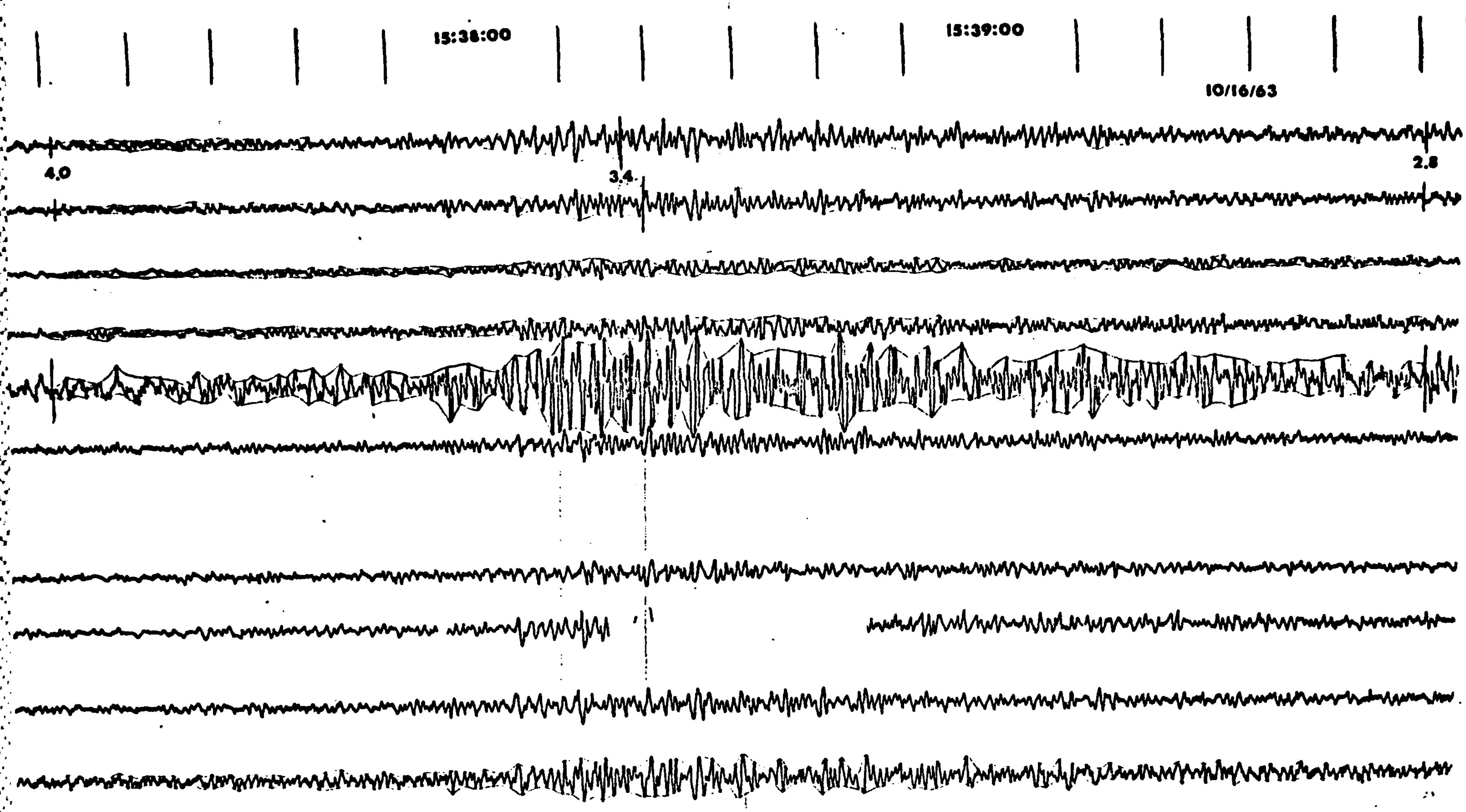


Figure 18. Cumberland Plateau Seismic Observatory records of L_g phase from October 16, 1963 earthquake.

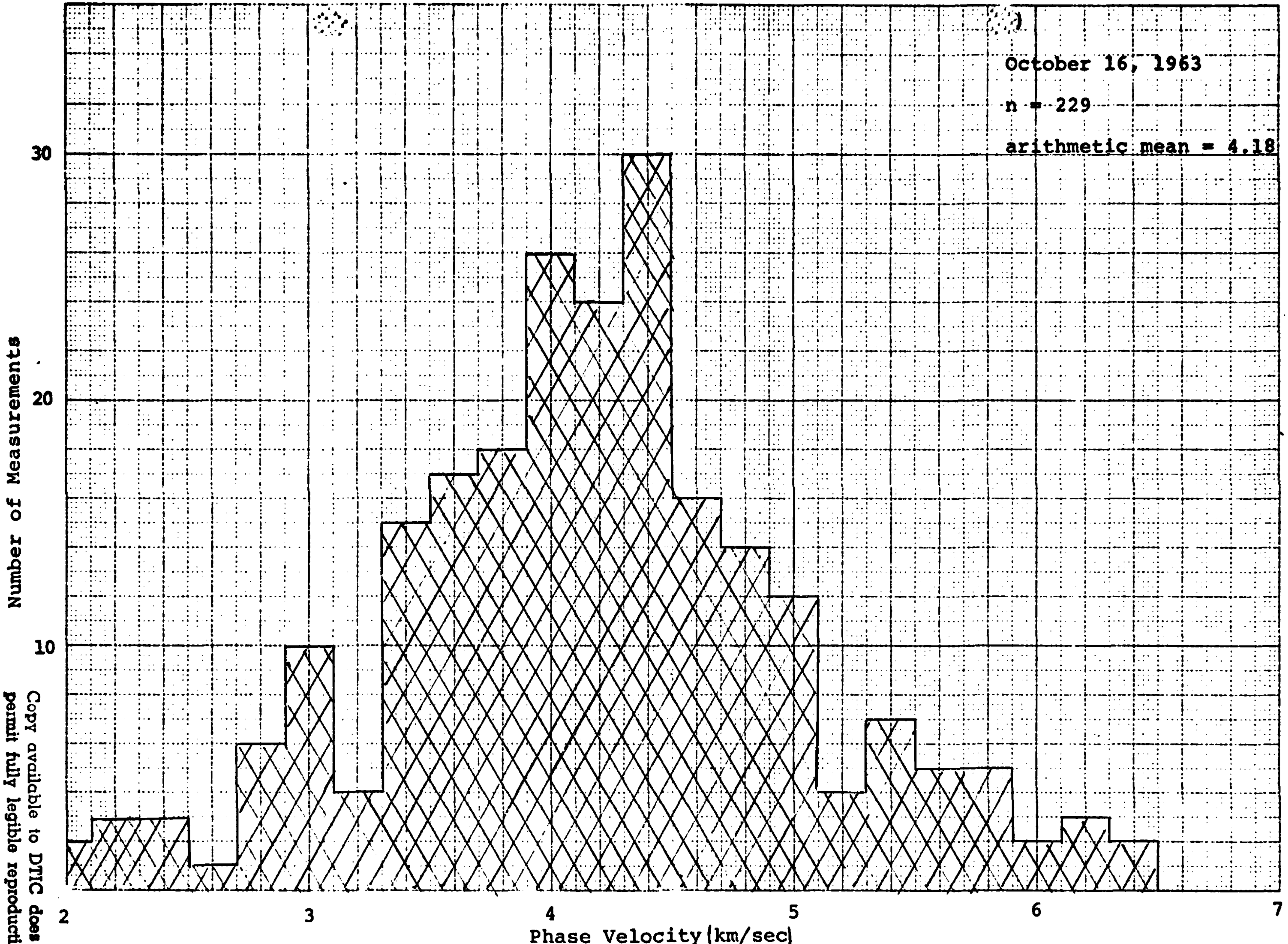


Figure 19. Phase velocity histogram from CPO records of October 16, 1963 earthquake.

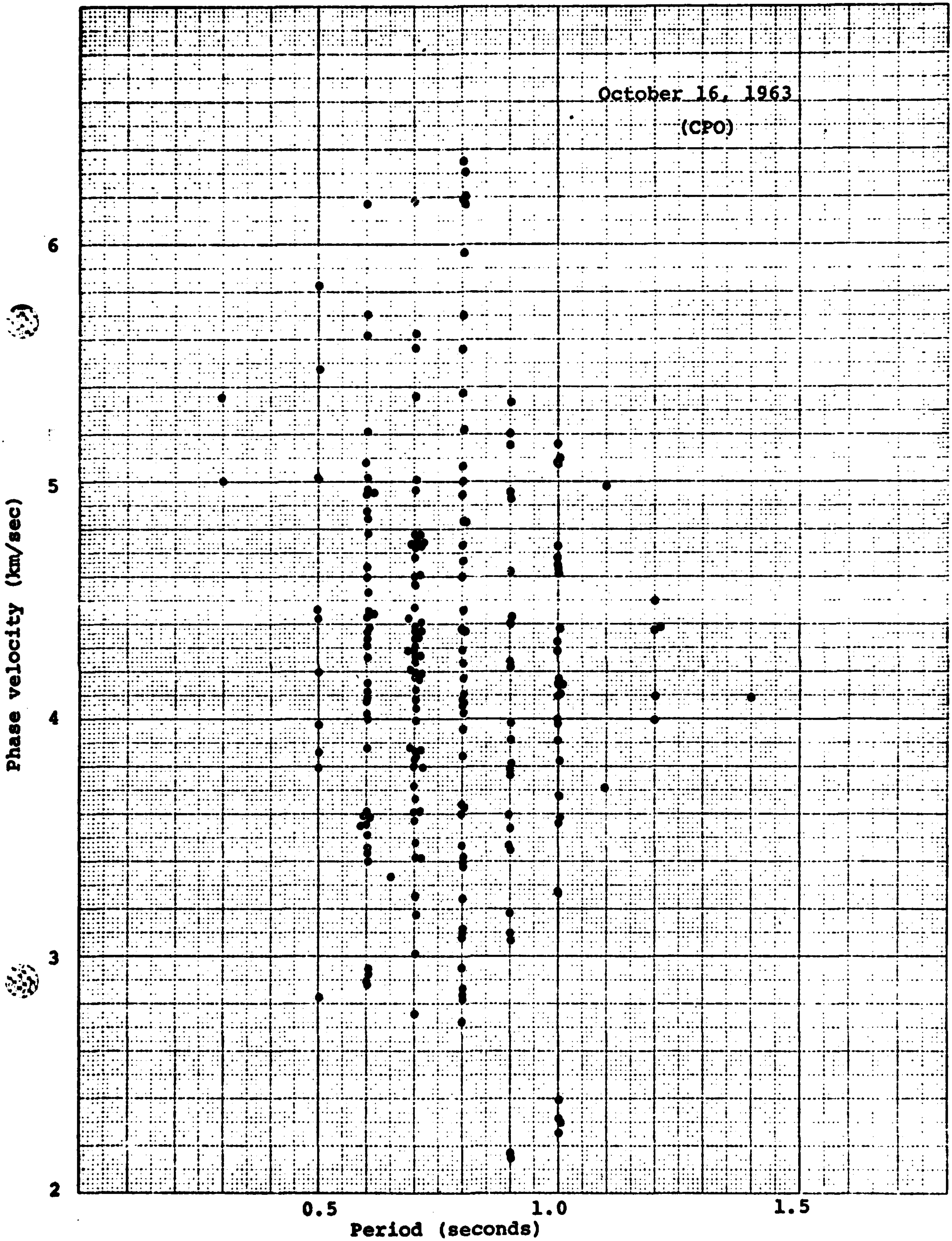


Figure 20. Phase velocity vs frequency from CPO records of October 16, 1963 earthquake.

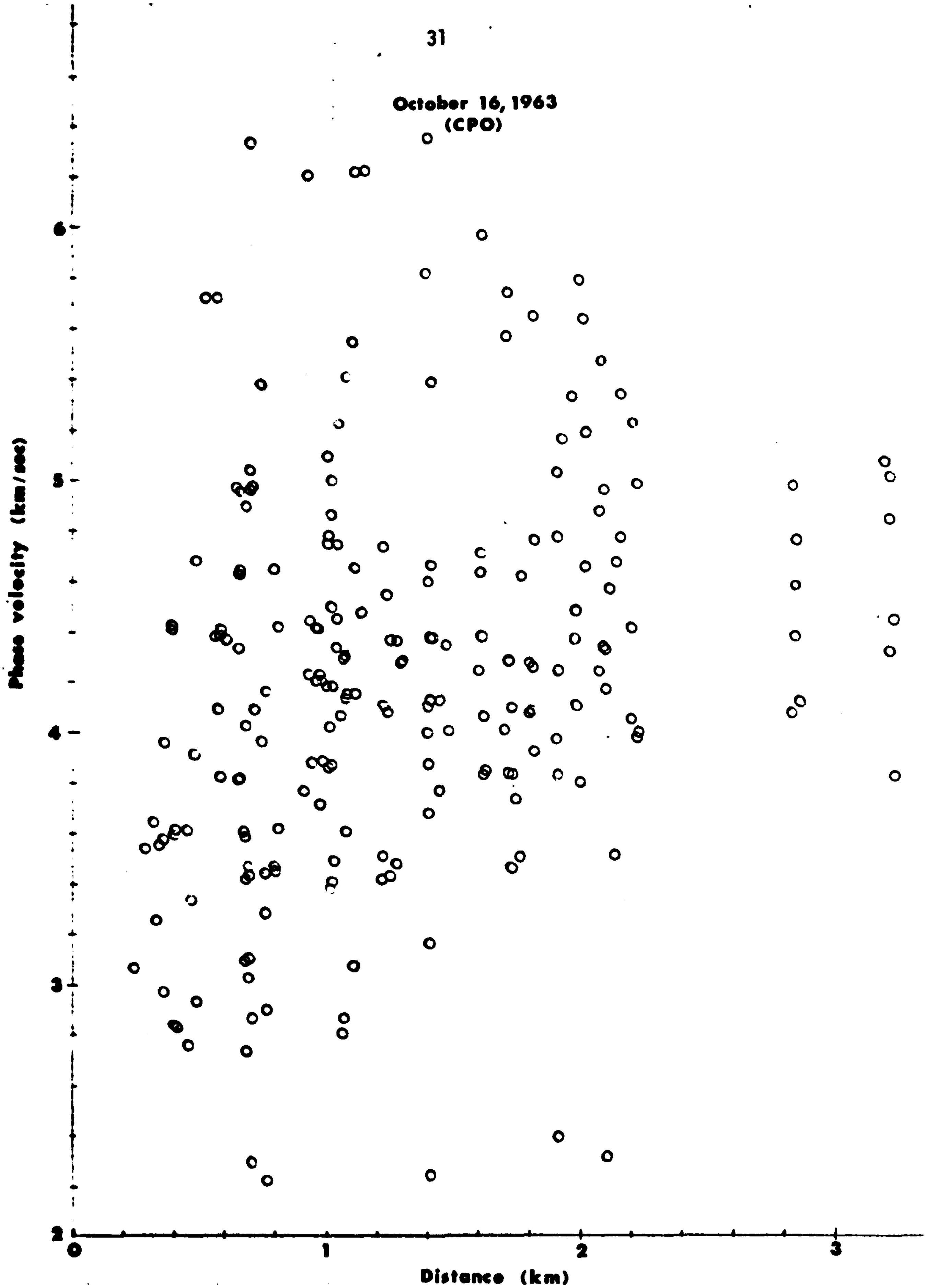


Figure 21. Phase velocity vs sensor distance.

B. Evaluate the use of the long period hydrophone data to determine long period energy content.

Each of these studies is discussed seperately below.

A. M_s-m_b studies.

The short and long period seismic records from the Point Arena system have been examined for 155 NTS events and 2 Aleutian events. On the long period records 21 NTS and 1 Aleutian event were recorded with sufficient signal to noise ratios to allow assignment of a surface wave magnitude. International Seismological Centers (ISC) body wave magnitudes were used. All of the data and source parameters are tabulated in Table II. The resultant M_s-m_b plot for this data is presented in Figure 22. Also shown in Figure 22 are the M_s-m_b results of Liebermann and Pomeroy for explosions and earthquakes in the Western United States. The M_s-m_b relationships for explosions, M_s-m_b=1.8, is shown together with an earlier Gutenberg and Richter relationship relating M_s and m_b for earthquakes. The results from the Point Arena station clearly substantiate the earlier work on M_s-m_b separation in the Western United States but in this context much more importantly, the data indicate the usefulness of OBS long period systems at regional distances as an aid to the discrimination problem.

The lowest body wave magnitude for the events studied here is 5.3. However, it should be noted that the Point Arena instruments were designed to have a flat response to displacement for periods between 15 and 100 seconds. During most of the operational period, the magnification of the system was 1500 - occasional plus 10 db or minus 10 db - and the system had significant response in the period range of 4 to 9 seconds - thus the microseism noise level in that band was very high. By notching out the microseisms and shaping the response, it would appear that at least an order of magnitude increase in the detection could be achieved over that of the Point Arena system.

The NTS explosions at the lower end of the range studied include KNOX, NOGGIN, TIJERAS and MINIATA. The first three had yields in the low to intermediate range while the published yield of MINIATA is 80 kilotons.

B. Use of long period hydrophone data to evaluate long period energy content.

The long period hydrophone recorded clear signals from the 21 events recorded on the long period vertical seismograph. The signal amplitudes on the long period hydrophone record are of the order of half of the amplitudes on the vertical long period seismograph. The microseism amplitudes are approximately one half. Therefore, the hydrophones provide a highly useful record of the 20 second surface waves and could be used alone to evaluate the long period energy present in a given signal. Because this report will receive wider distribution than a previous report which contained sample records of the long period seismograph and hydrophone signals, we are including those illustrations in this report as Figures 23, 24, and 25. The source data for these events is given in Table III.

TABLE II

Date	Event	Yield (kt)	Origin Time	Amplitude: 20 sec z P-P	Amplitude: Hydrophone	Distance (degrees)	M_{s20}	m_b ISC
06/30/66	Halfbeak	300	22:15	27mm	14mm	6.87°	4.5	6.1
12/20/66	Greeley	825	15:30	30mm	18mm	6.79°	4.5	6.3
05/20/67	Commodore	I-250	15:00	10.5mm	5 max.	7.1°	4.06	5.8
05/23/67	Scotch	150	14:00	10.5mm	7.5mm	6.8°	4.06	5.7
05/26/67	Knickerbocker	71	15:00	8.5mm	4mm	6.74°	4.0	5.4
01/19/68	Faultless	I	18:15	44mm	~23mm	6.84°	4.68	6.3
02/21/68	Knox	L-I	15:30	3mm (drawn in)	Present	7.1°	3.5	5.8
04/26/68	Boxcar	1200	15:00	29mm	~12mm	6.75°	4.5	6.2
06/15/68	Rickey	L-I	13:59	13mm (16 sec)		6.87°	4.15	5.9
06/28/68	Chateaugay	L-I	12:22	8mm	~2-3mm	6.74°	3.9	5.3
08/29/68	Sled	L-I	22:45	10mm		6.85°	4.04	none reported
09/06/68	Noggin	L-I	14:00	6mm	2-3 max.	7.1°	3.8	5.5
12/19/68	Benham	1100	16:30	~130 mm clipped 6mm at .5 sec m_b=6.8		6.75°	5.15	6.3
05/07/69	Purse	L-I	13:45	15mm	~7-8 mm	6.72°	4.2	5.5
09/16/69	Jorum	LM	14:30	55mm	25-30mm clipping	6.74°	4.8	6.1
10/02/69	Milrow (ADAK)	LM	22:06	4mm on SP4		41°	$m_b \approx$ 6.32	6.4
10/08/69	Pipkin	I	14:30	10mm	—	6.77°	4.04	5.6
10/29/69	Calabush	110	22:01	6mm		7.08°	3.8	5.6
03/26/70	Handley	>1Mt	19:00	105mm	~20mm	6.69°	5.06	6.4
10/14/70	Tijeras	L-I	14:30	~5mm max.		7.15°	3.74	5.5
07/08/71	Miniata	80	14:00	~3mm max.		7.10°	3.55	5.5
11/06/71	Cannikan	< 5MT	22:00	10mm		40.9°	5.15	6.6

List of NTS and Aleutian explosions used in OBS M_s-m_b study.

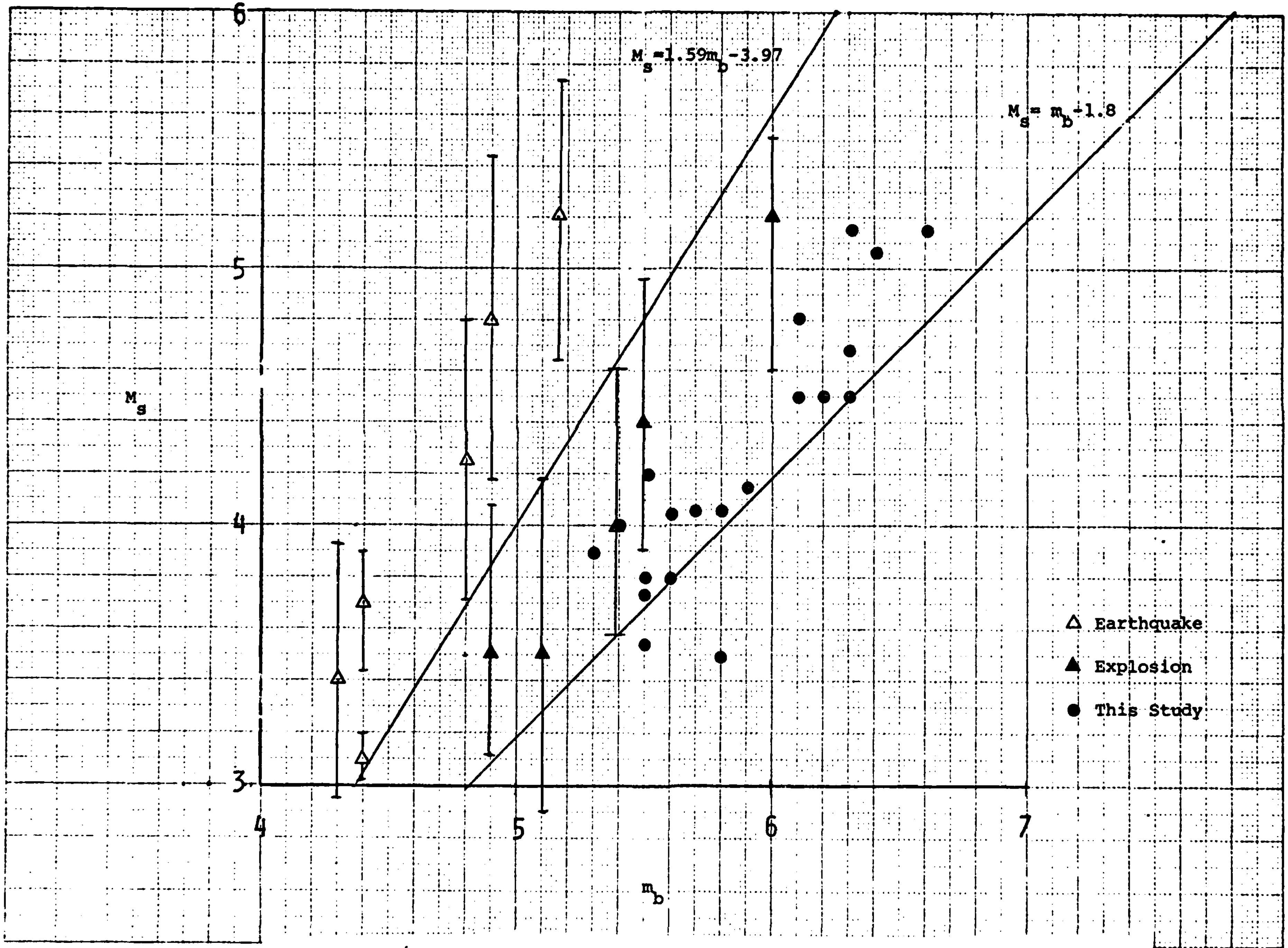
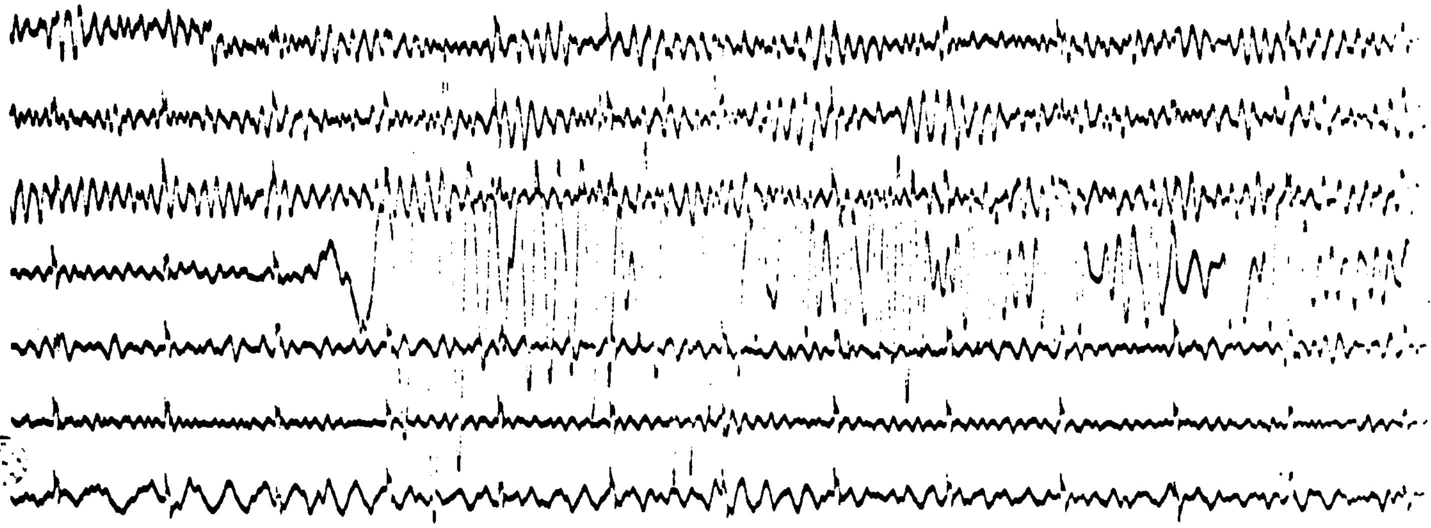


Figure 22. M_s vs m_b plot of NTS and Aleutian explosions recorded

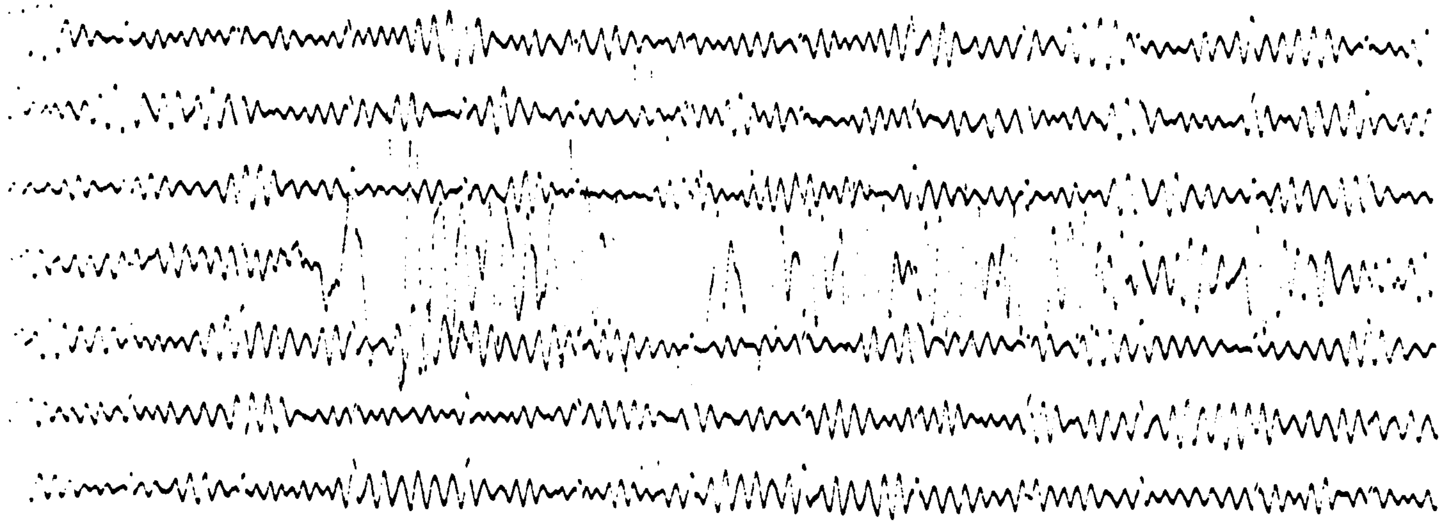
Table III OBS Events

Date	Origin Time	Yield
5-7-69	13:45:00	L - I
5-26-67	15:00:00	71 Kt
5-23-67	14:00:00	150 Kt
5-20-67	15:00:00	250 Kt
6-30-66	22:15:00	300 Kt
12-20-66	15:30:00	825 Kt
4-26-68	15:00:00	1200 Kt

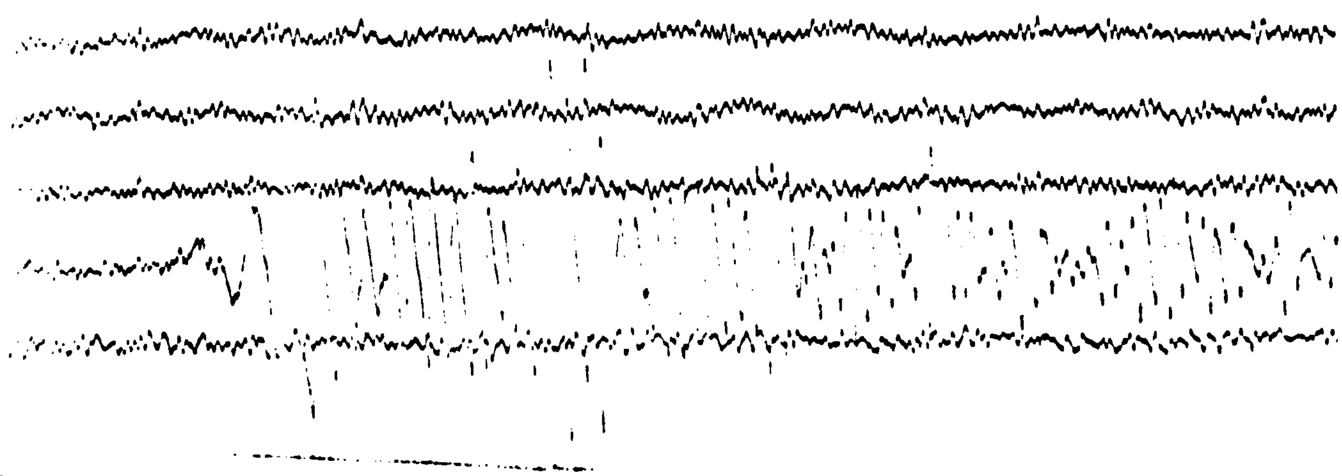
List of NTS explosions for which records are presented in Figures 23-25.



1200 Kt



825 Kt



300 Kt

Figure 23. OBS seismometer records from Point Arena, California for NTS events.

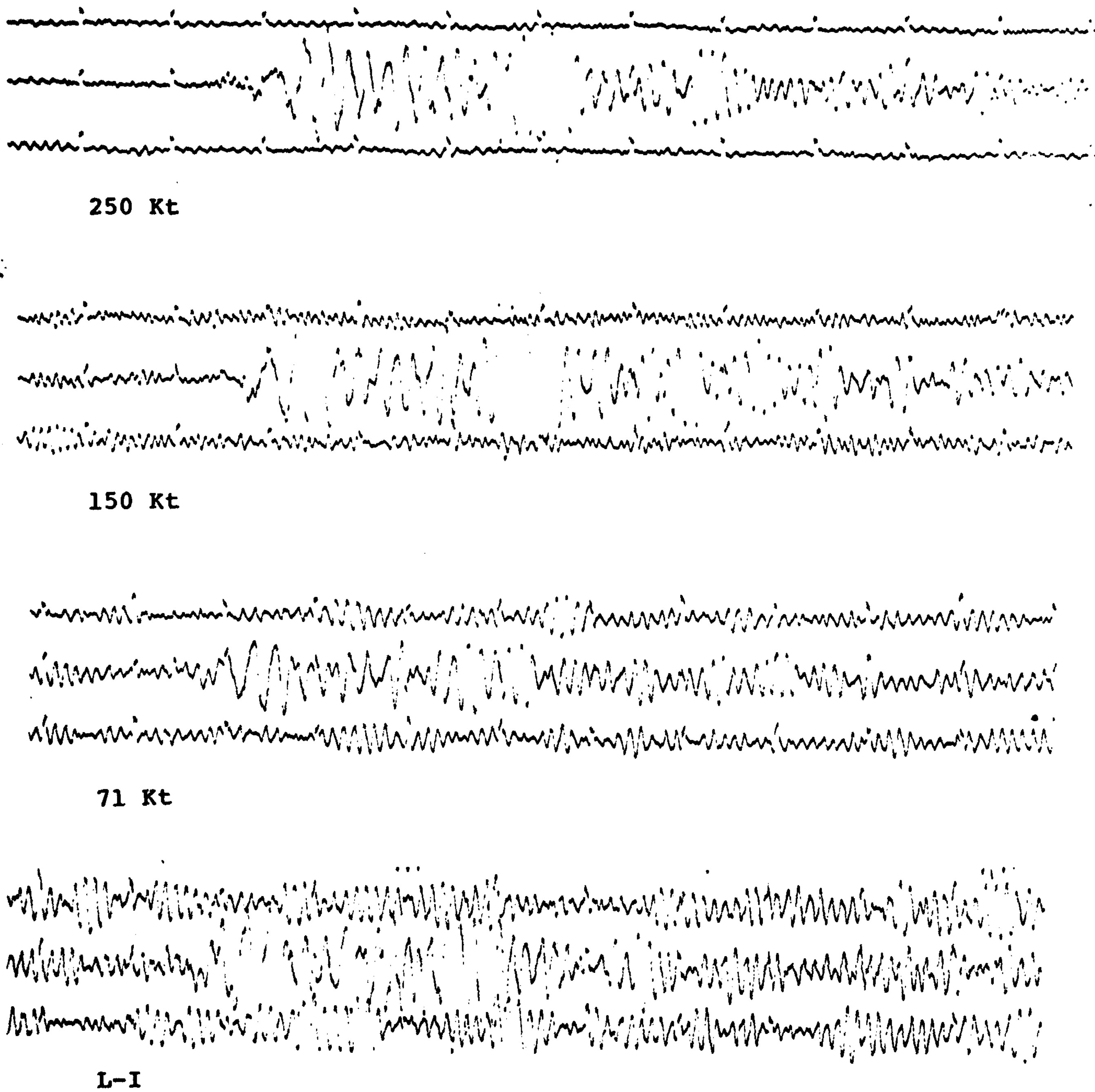


Figure 24. OBS seismometer records from Point Arena, California for NTS events.

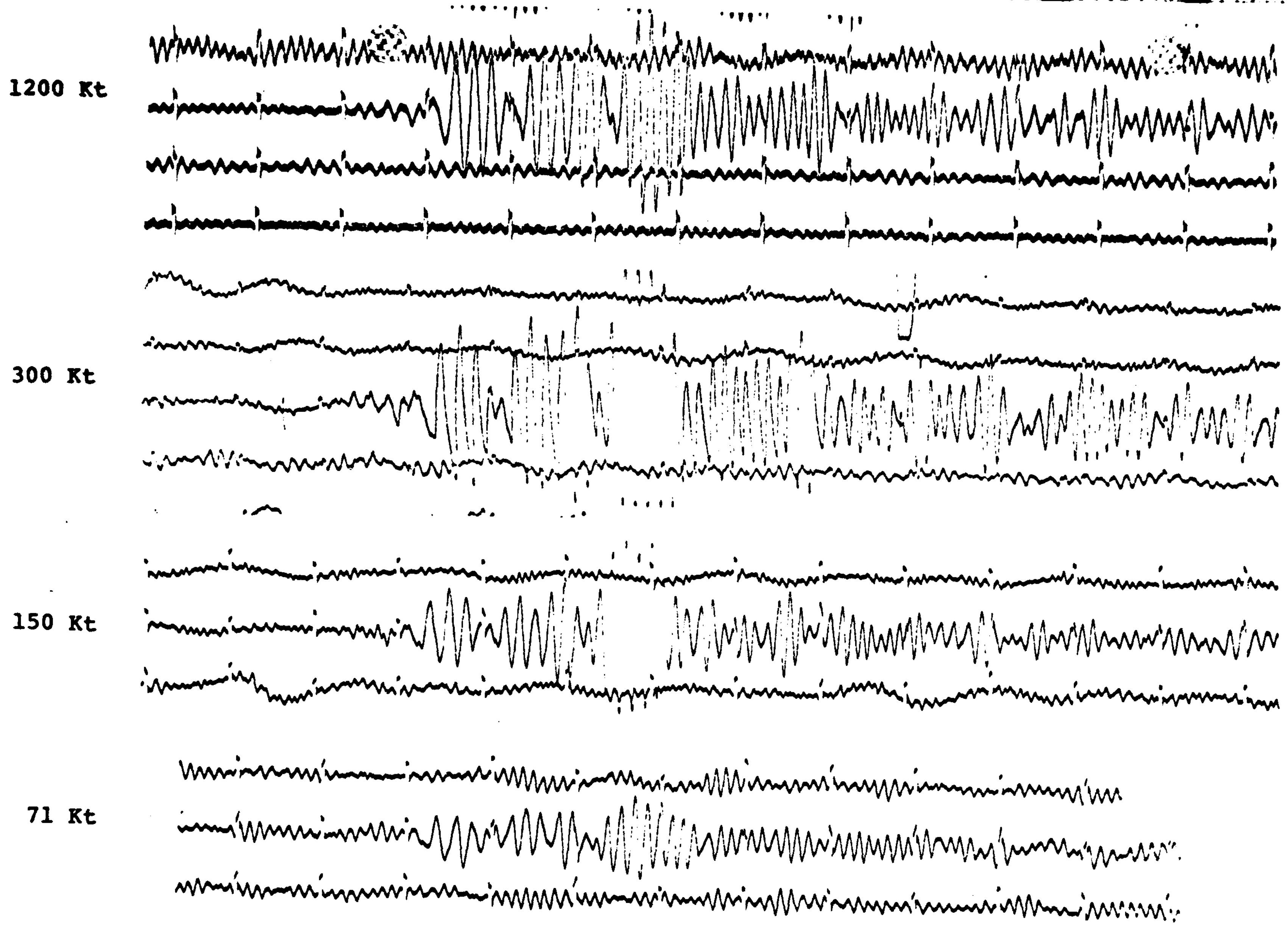


Figure 25. OBS hydrophone records from Point Arena, California for NTS events.

APPENDIX A

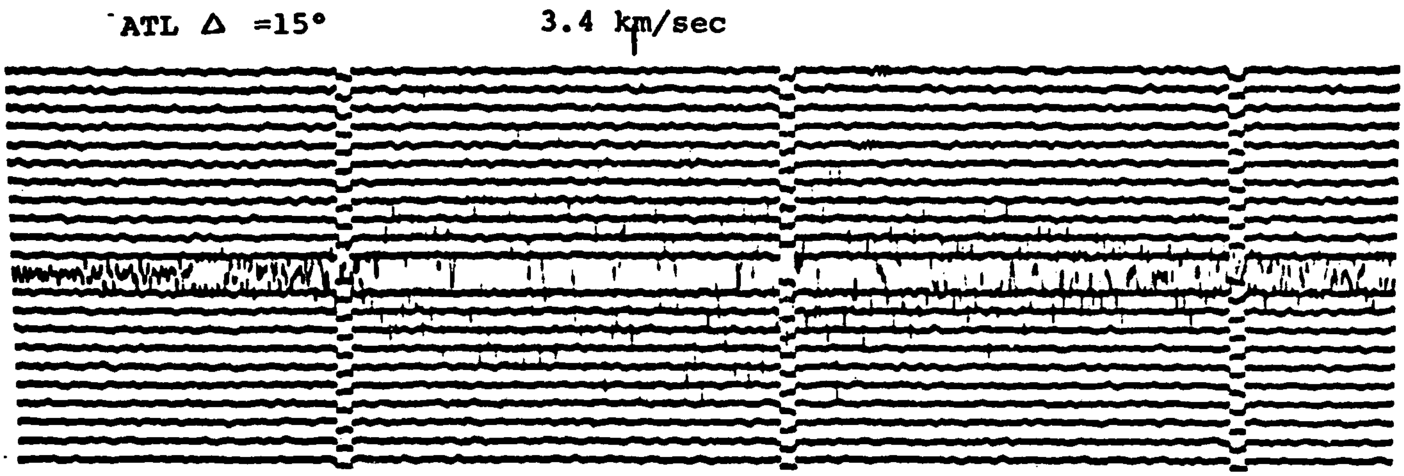


Figure A-1 Record of June 15, 1973 recorded at ATL showing L_g

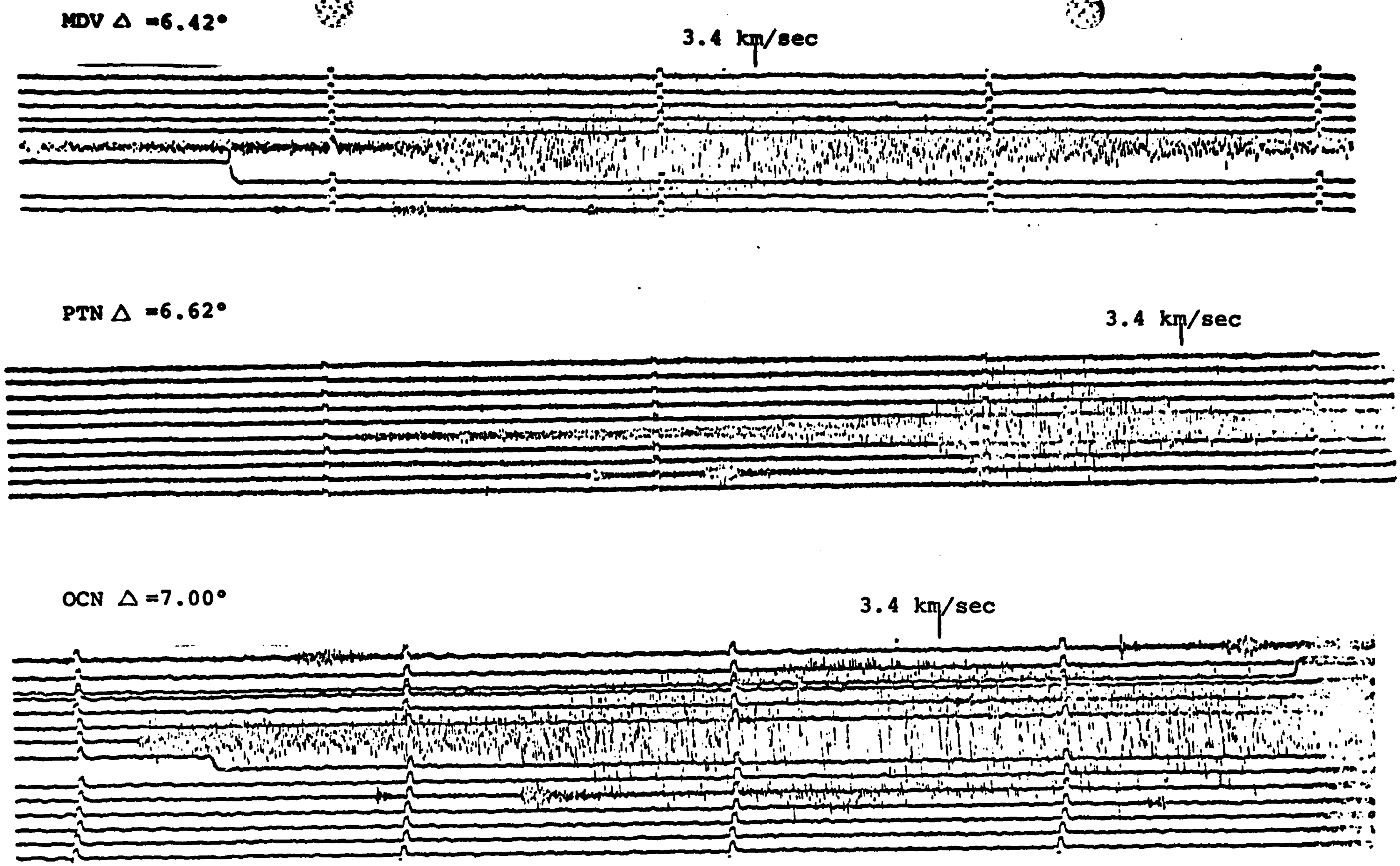


Figure A-2 Earthquake of October 23, 1975 recorded at MDV, PTN, and OCN showing L_g

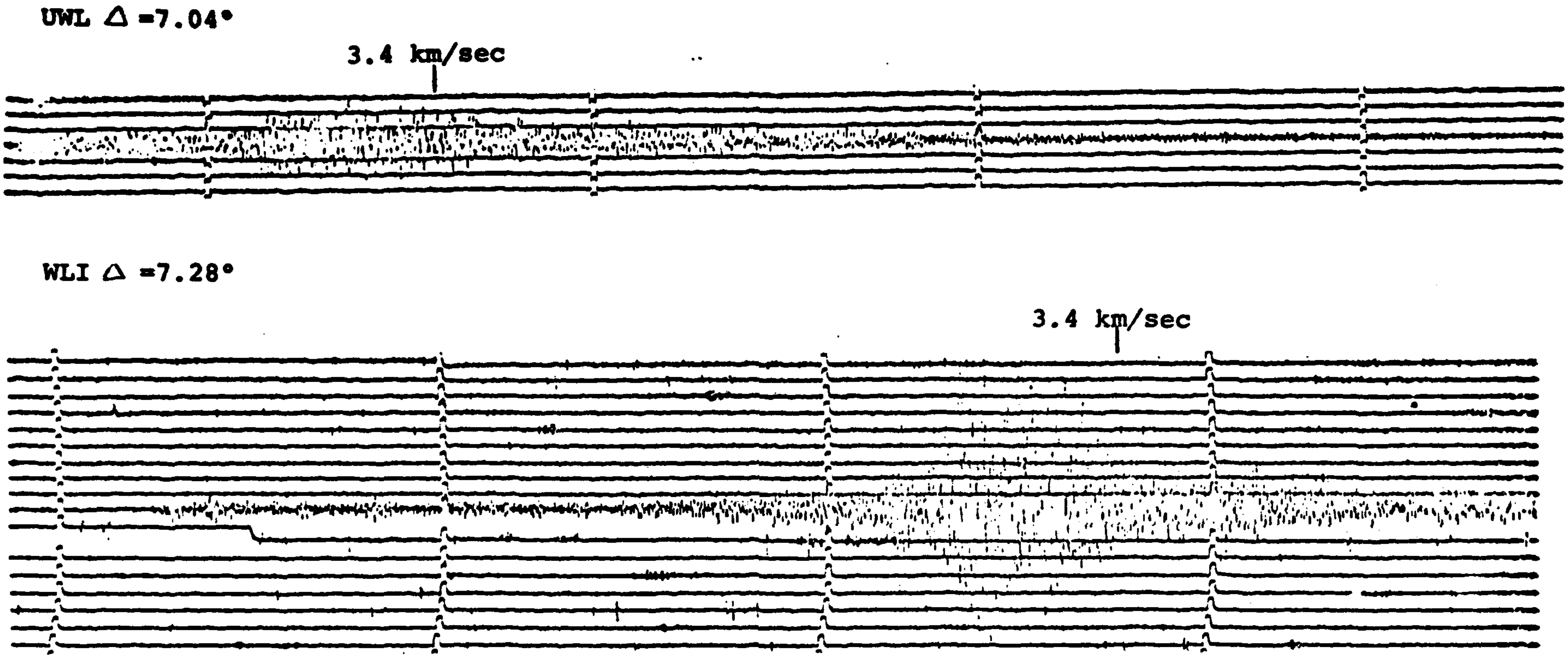


Figure A-3 Earthquake of October 23, 1975 recorded at UWL and WLI showing L_g.

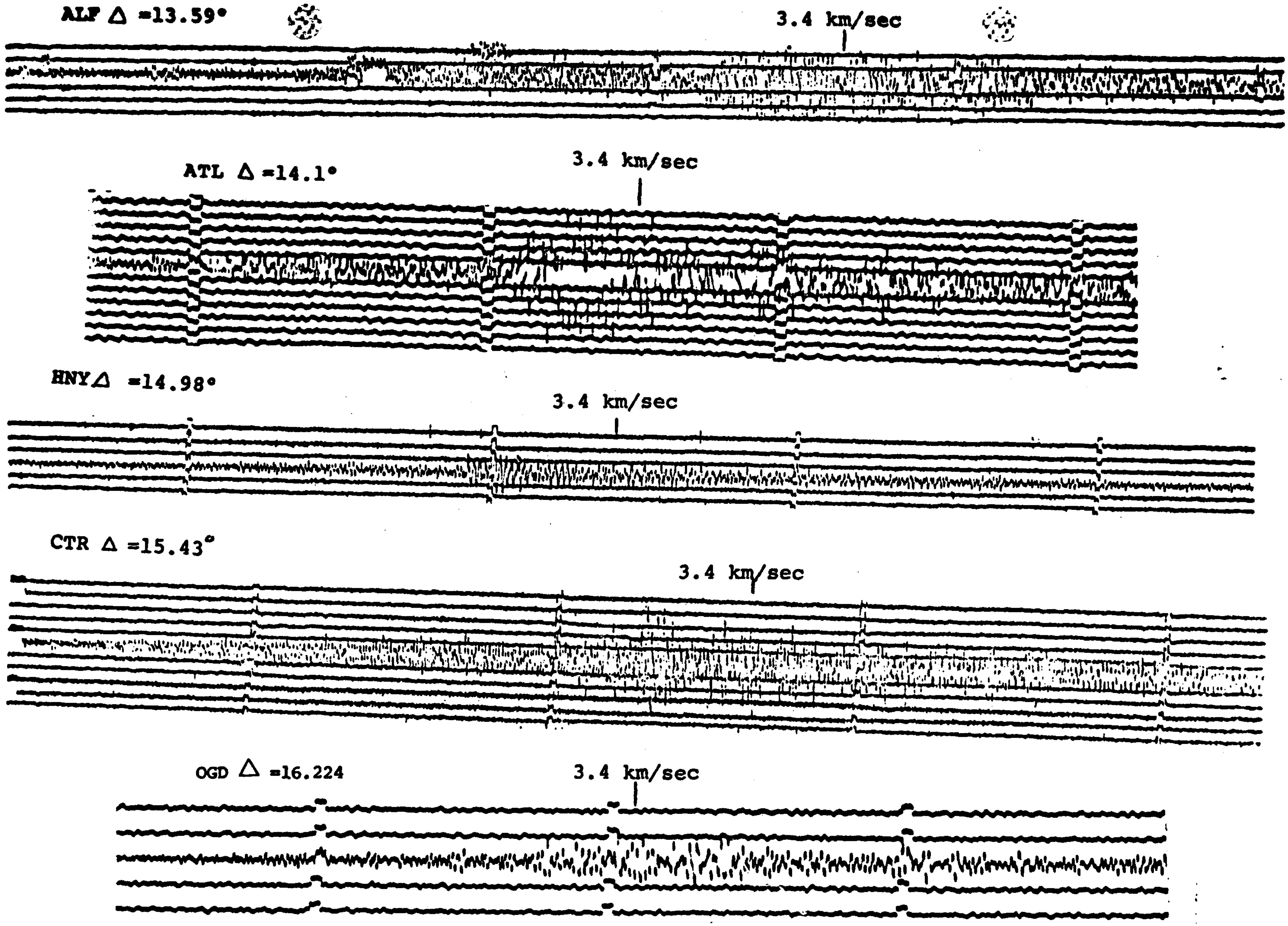


Figure A-4 Earthquake of July 9, 1975 recorded at ALF, ATL, HNY, CTR and OGD showing L_g.

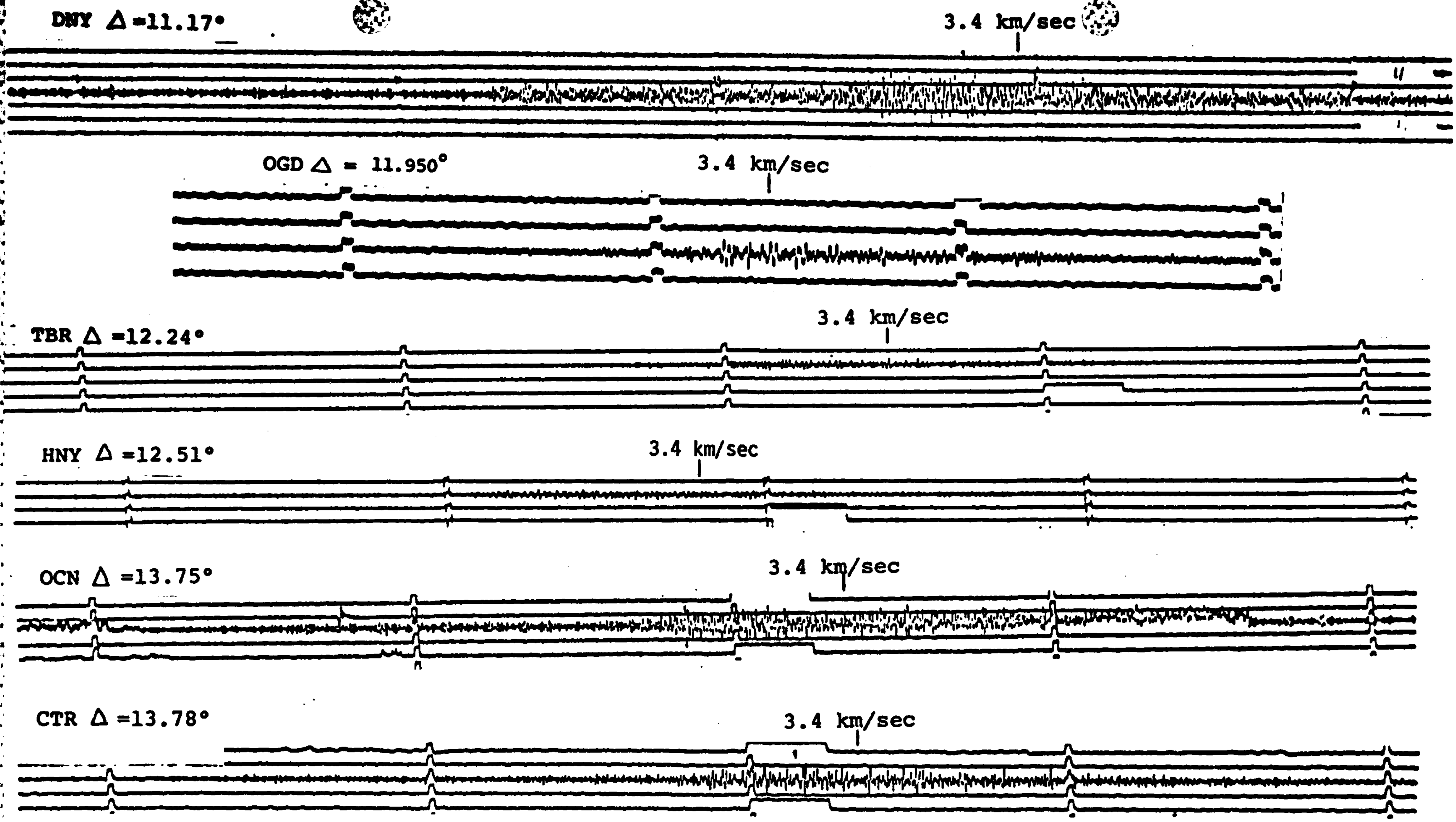


Figure A-5 Earthquake of August 29, 1975 recorded at DNY, OGD, TBR, HNY, OCN and CTR showing L_g.

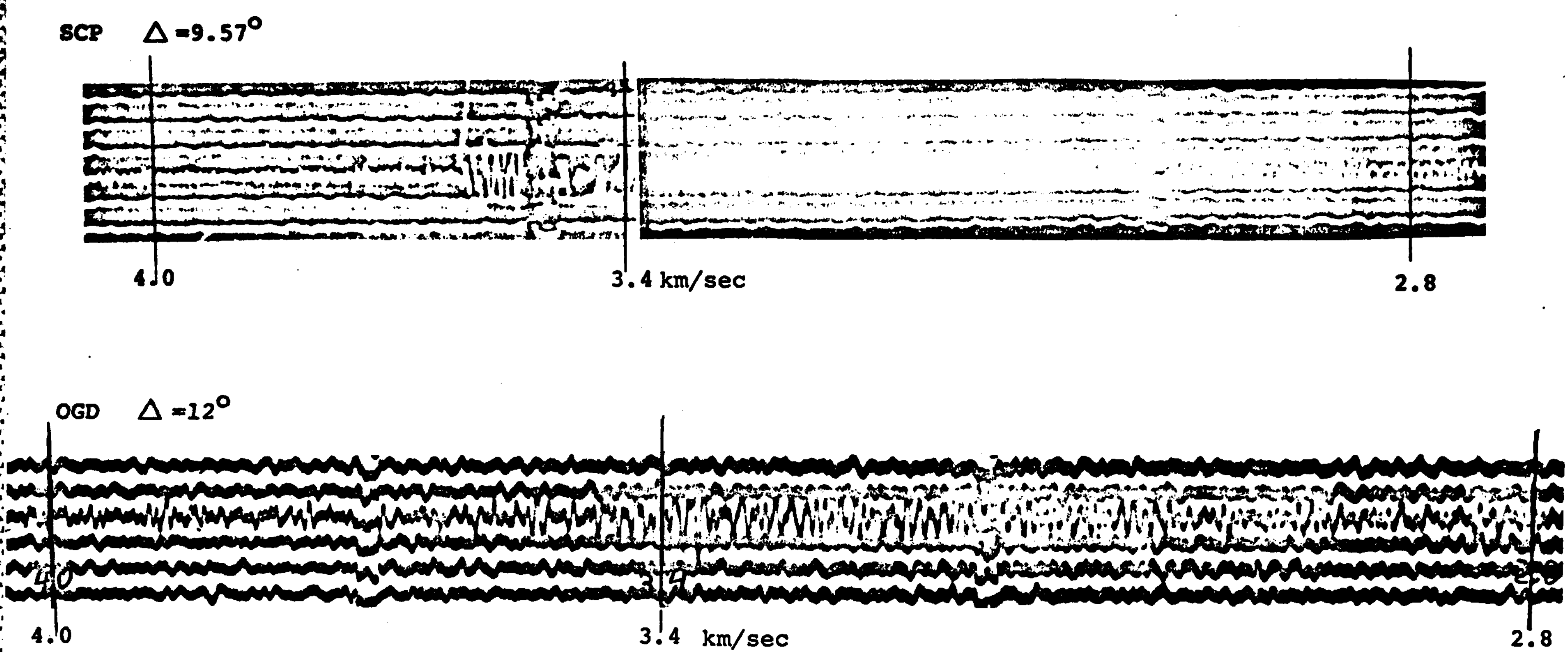


Figure A-6 Records of August 14, 1965 earthquake recorded at SCP and OGD showing L_g.

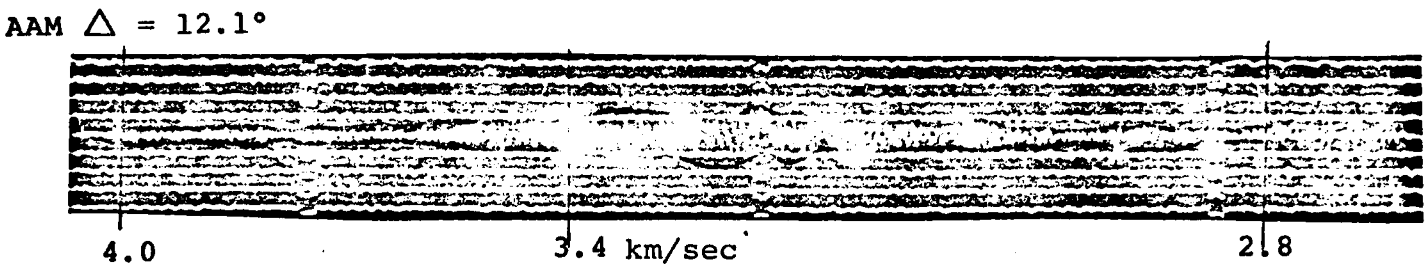


Figure A-7 Record of SALMON explosion showing L_g.

APPENDIX B

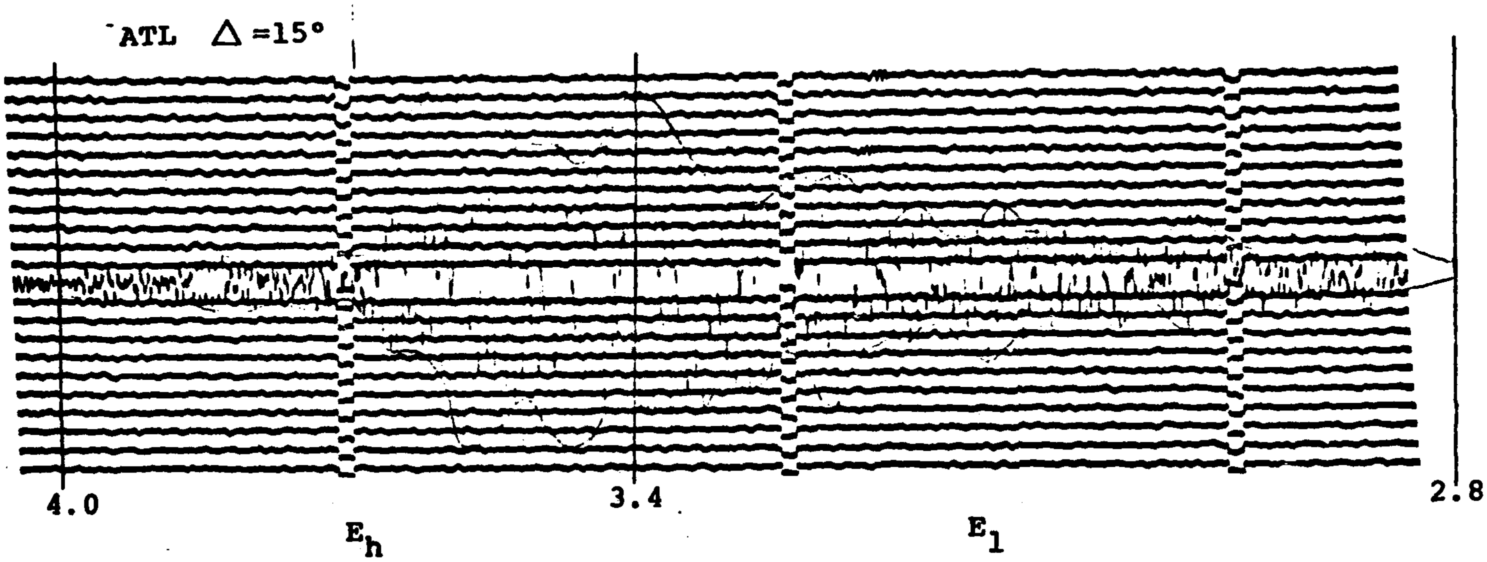


Figure B-1 Record of June 15, 1973 earthquake showing L_g energy distribution.

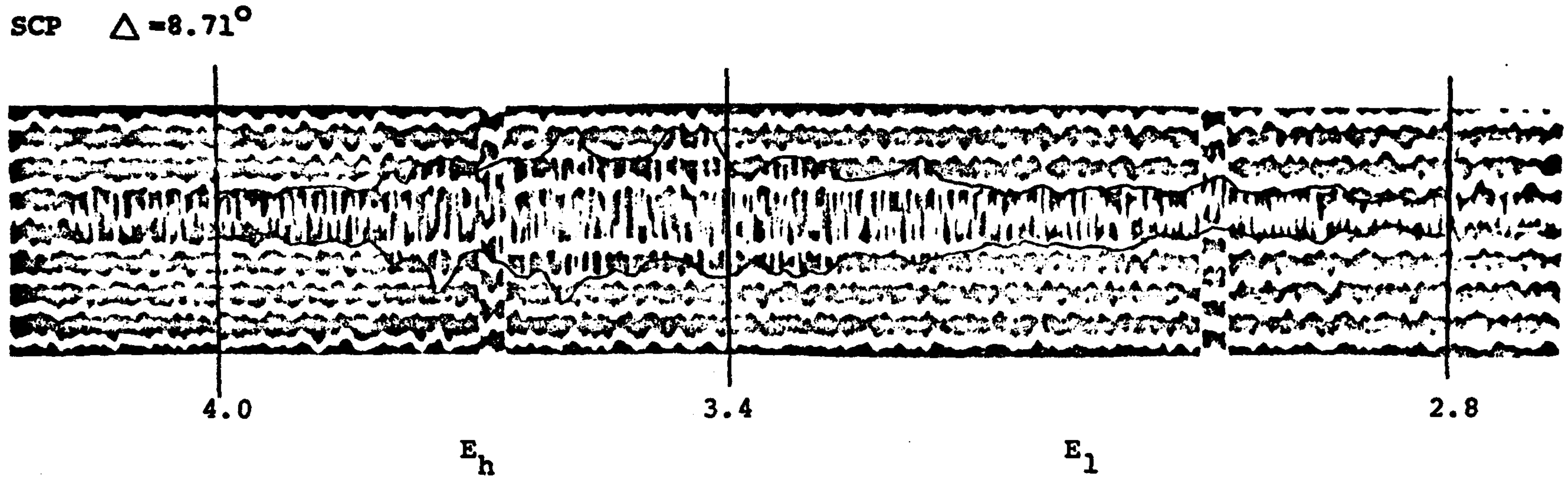


Figure B-2 Record of May 4, 1963 earthquake showing L_g energy distribution.

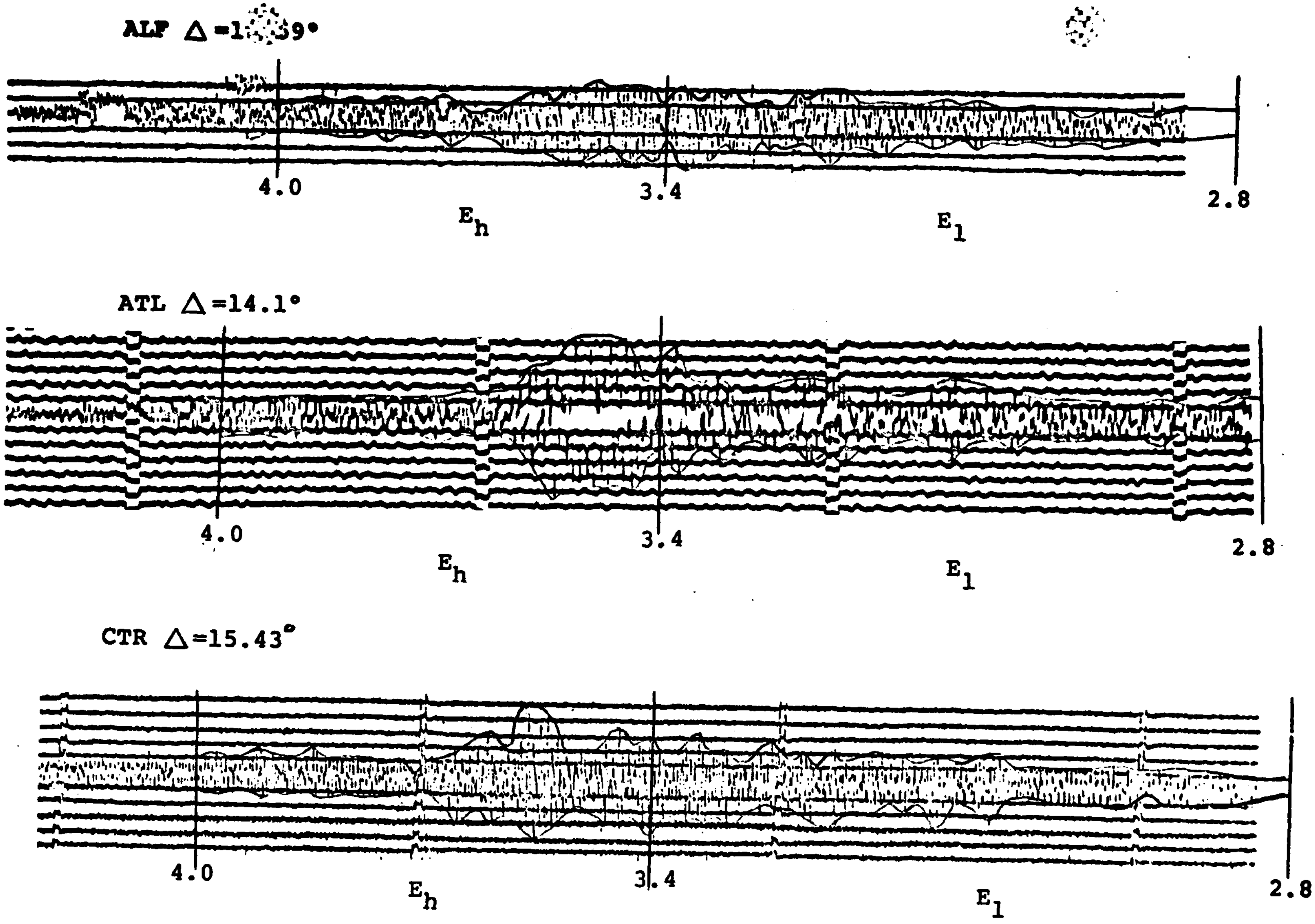


Figure B-3 Records of July 9, 1975 earthquake showing L_g energy distribution.

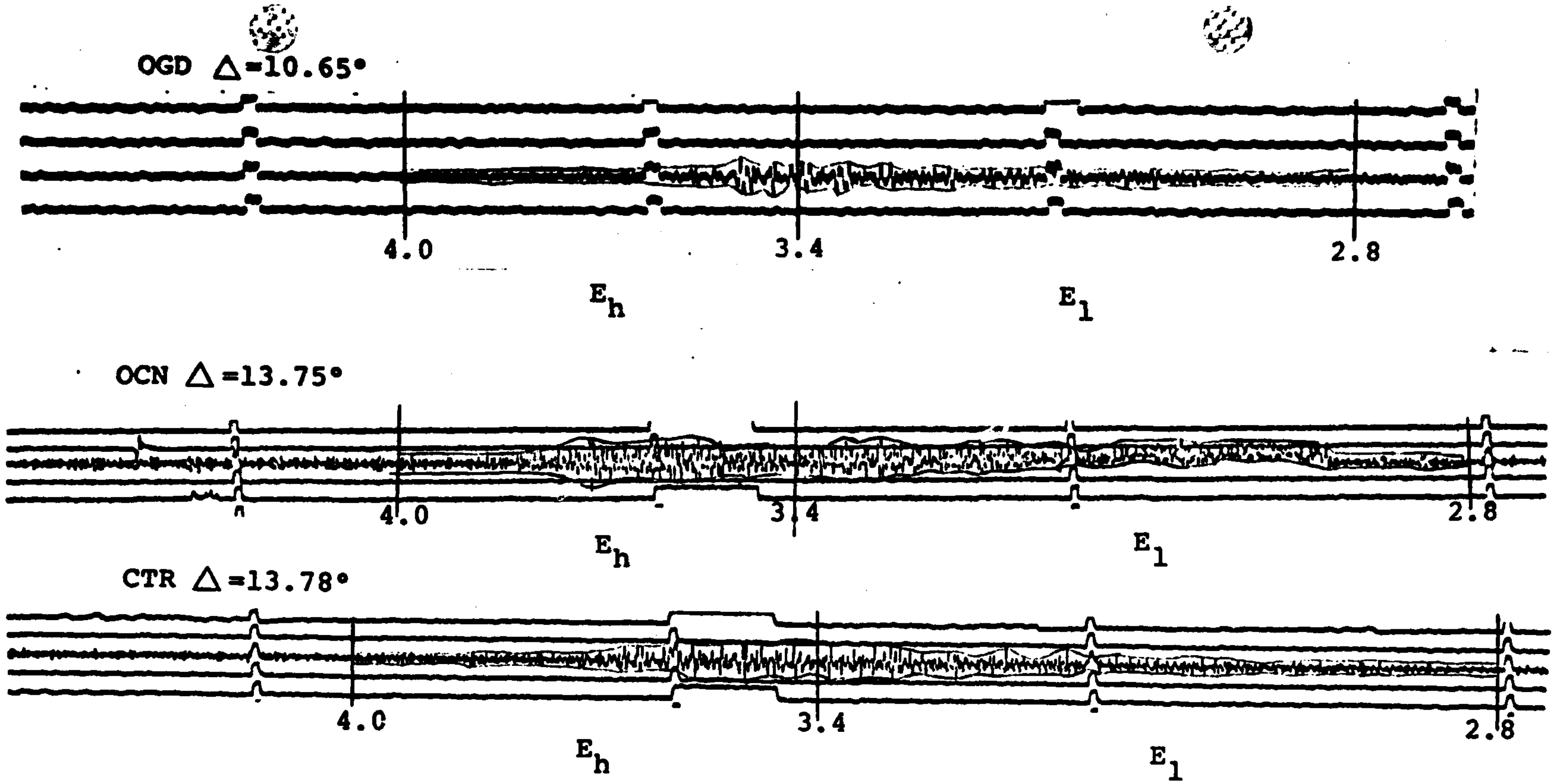


Figure B-4 Records of August 29, 1975 earthquake showing L_g energy distribution.

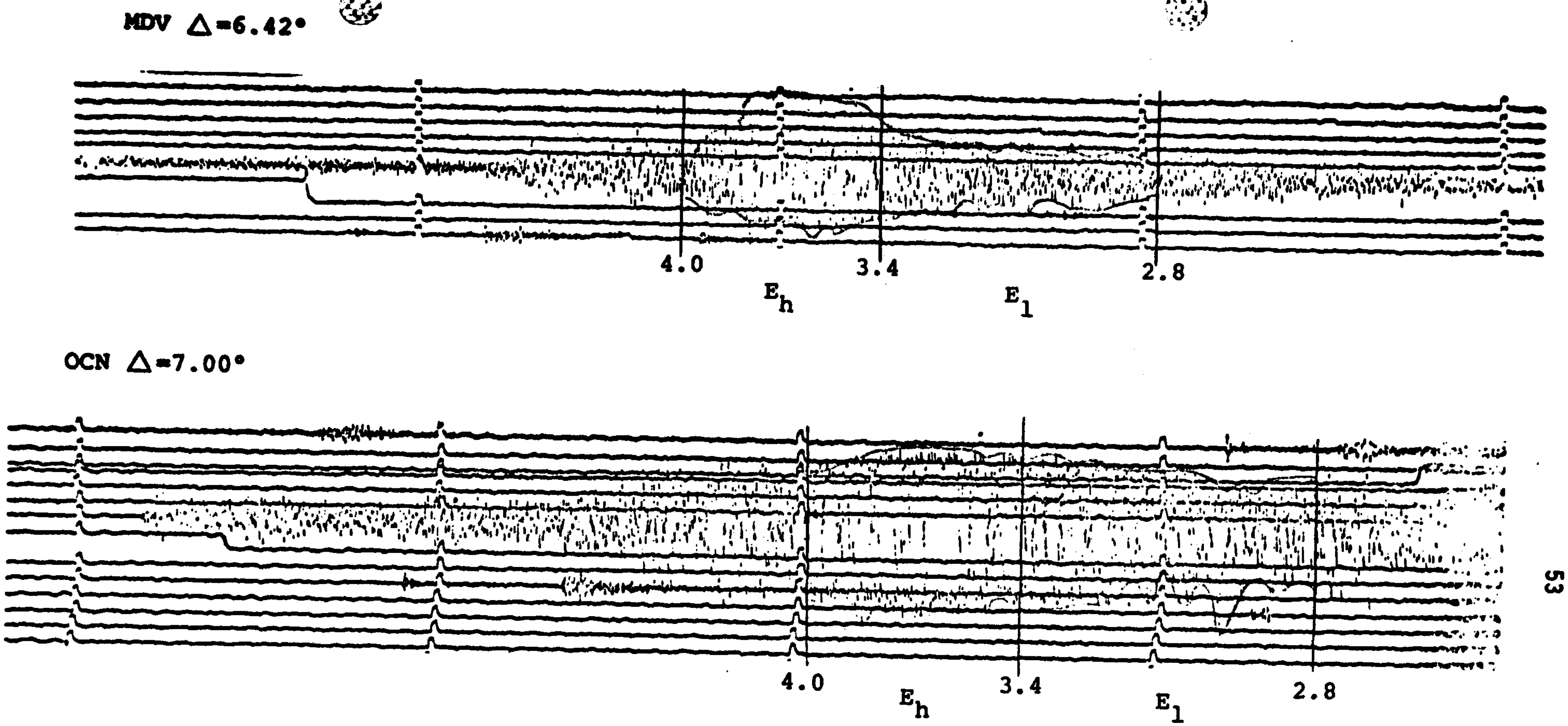


Figure B-5 Records of October 23, 1975 earthquake showing L_g energy distribution.

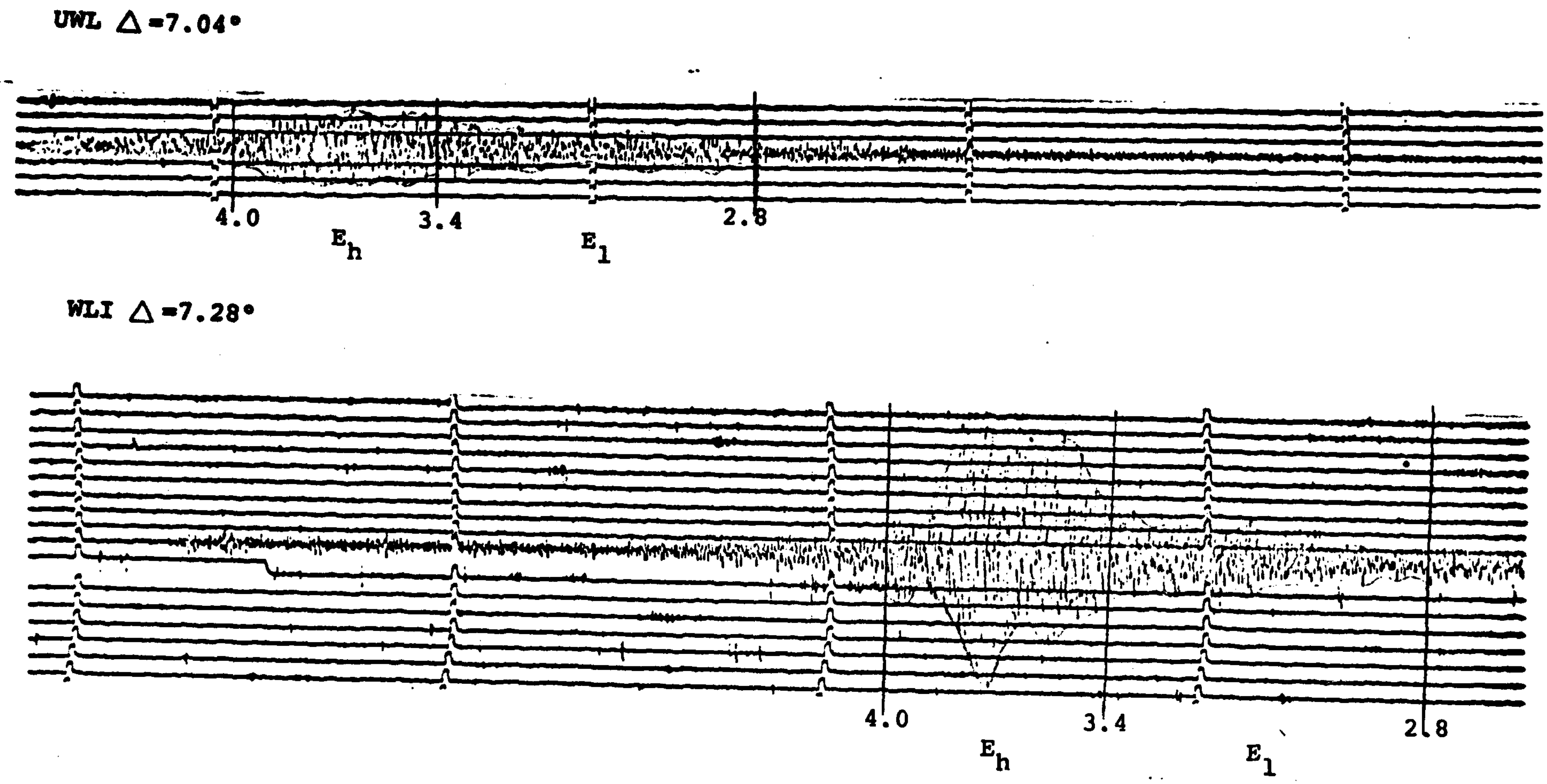
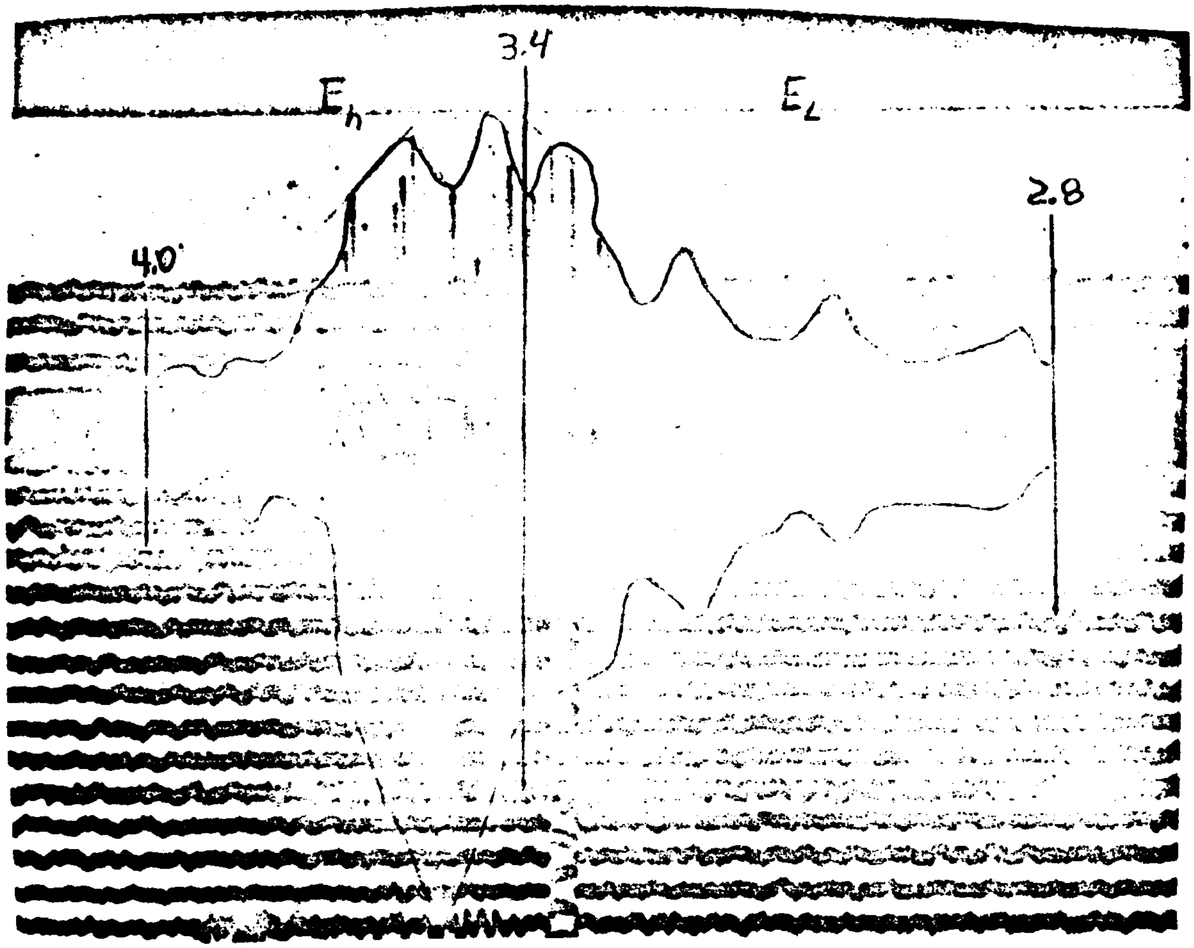
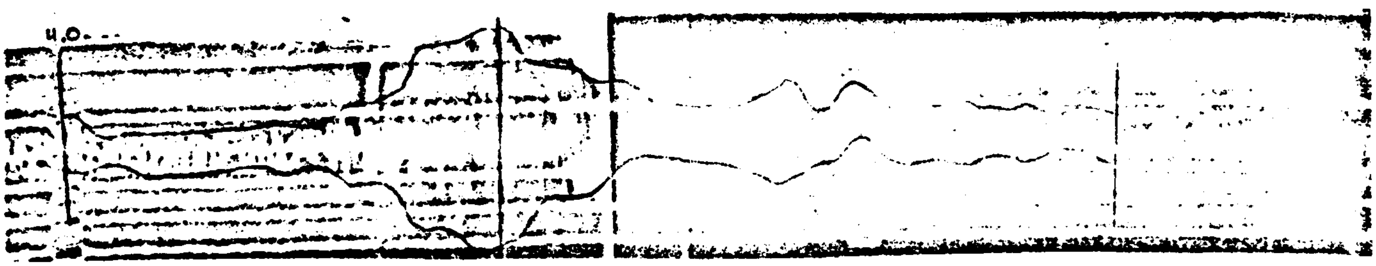


Figure B-6 Records of October 23, 1975 earthquake showing L_g energy distribution.

SCP $\Delta = 5.54^{\circ}$



AAM $\Delta = 6.65$



4.0 3.4 2.8

E_h E_1

Figure B-7 Records of August 14, 1965 showing L_g energy distribution.

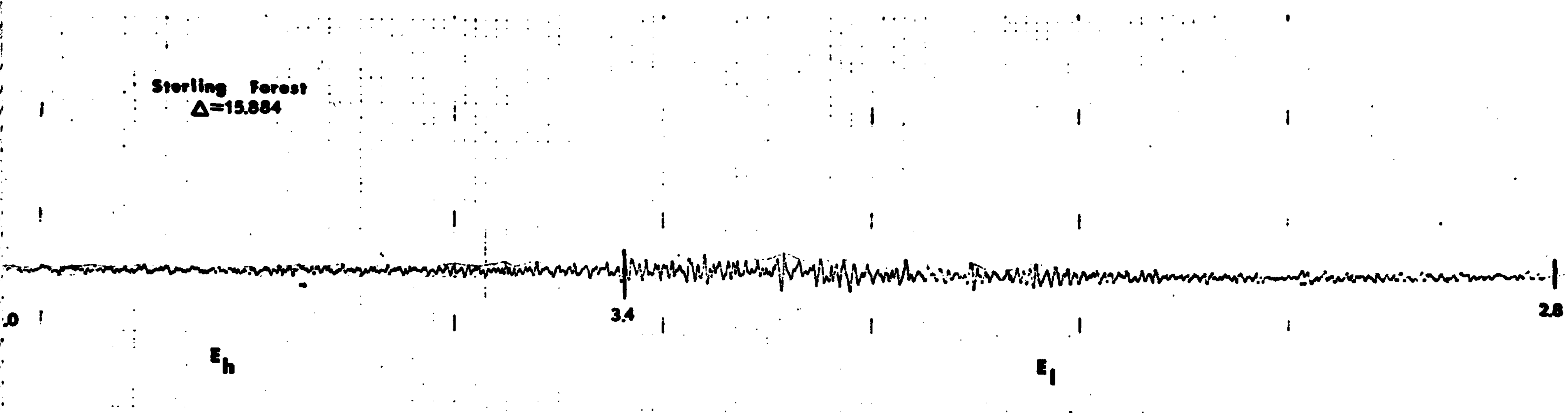


Figure B-8 Record of SALMON showing L_g energy distribution.

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